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XR-3 SURFACE EFFECTS SHIP TEST CRAFT: A MATHEMATICAL MODEL AND SIMULATION PROGRAM WITH VERIFICATION

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THESIS

XR-3 SURFACE EFFECTS

SHIP TEST CRAFT:

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PROGRAM WITH VERIFICATION

by

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Thesis Advisor: Alex Gerba, Jr.

December 1973

XR-3 Surface Effects Ship Test Craft:

A Mathematical Model and Simulation Program with Verification

by

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ABSTRACT

The digital computer simulation of the six degrees of freedom equations of motion for the XR-3 captive air bubble testcraft is presented. The origin of this computer program is the SES Loads and Motion Program developed by Oceanics Inc. for the Bell 100 ton (100B) surface effect ship. Modifications and procedures used in the revision of the subroutines to convert the L & M Program from the 100B model to the XR-3 model is documented. Measurement data from XR-3 test runs are used to verify the model for steady-state operating conditions in calm water. Computer output for turn maneuvers in calm waters and for regular sea conditions are included.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF DRAWINGS

TABLE OF SYMBOLS AND ABBREVIATIONS

AEROD	=	aerodynamics
BOWSL	=	bow seal
FORIT	=	fourier analysis
FXAED	=	aerodynamic force in x direction
FXBS	=	bow seal force in x direction
FXPWAV	=	bubble-type force in x direction due to drag between bubble and wave surface
FXRUD	=	rudder force in x direction
FXSS	=	stern seal force in x direction
FXSW	=	sidewall force in x direction
I_{xx}	=	mass moment of inertia about x-axis
I_{xz}	=	mass moment of inertial about xz-axis
I_{yy}	=	mass moment of inertia about y-axis
I_{zz}	=	mass moment of inertia about z-axis
INCON	=	initial conditon
INTGRL	=	integral
K	=	roll moment
ℓ	=	length of craft (24 feet)
m	=	mass
m_b	=	mass of the air bubble
N	=	pitch moment
P=p	=	rotational velocity about x-axis
P_b	=	pressure in the bubble
PHI=Ø	=	roll angle
PROP	=	propeller

NSRDC	=	Naval Ship Research and Development Center
PSF	=	pounds per square foot
PSI=ψ	=	yaw angle
Q	=	rotational velocity about y-axis
Q_{in}	=	air flow rate in
Q_{out}	=	air flow rate out
R	=	rotational velocity about z-axis
RHS	=	right hand side
SAM	=	shear and moment
SIDWL	=	sidewall
STNSL	=	stern seal
ρ_a	=	standard atmospheric reference
T	=	arbitrary steady-state time
THETA=θ	=	roll angle
U	=	longitudinal velocity
V	=	lateral velocity
W	=	vertical velocity
X	=	horizontal distance in direction of motion
Y	=	horizontal distance perpendicular to direction of motion
Z	=	vertical distance
C.G.	=	center of gravity
psf	=	pounds per square foot
SES	=	Surface Effect Ship
ACV	=	Air Cushion Vehicle
CAB	=	Captured Air Bubble

plenum chamber	=	cavity beneath the wet deck of the XR-3, formed by the two sidewalls and the bow and stern seals
hump speed	=	speed at which testcraft overcomes large low velocity drag and begins to operate on the cushion of captured pressurized air

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I. INTRODUCTION

A. BACKGROUND

Conventional monohull displacement type ships are drag force limited to speeds of approximately 50 knots. A very cursory study of the frictional drag component and its direct dependence on the square of velocity will bear this out. It can be shown that the power plant requirements to overcome the drag force at the higher speeds requires such large plants that the ship weight increases significantly resulting in a speed barrier due to drag forces. The desire for speeds above the drag barrier speed has led to some new approaches in ship design. The Surface Effects Ship is one of these approaches.

Surface Effects Ship is a broad category which includes the ACV, Air Cushion Vehicle, GEM, Ground Effects Machine and the CAB, Captured Air Bubble. Navy Magazine of May 1967 has a very informative article on different ACV and GEM concepts. However, we shall confine our discussion to the CAB type of craft.

Captured Air Bubble Concept - The captured air bubble craft consists of rigid side walls with flexible soft seals between the water surface and the ship at bow and stern. This provides a chamber into which air is blown and captured. The resulting pressure in the plenum provides a vertical force sufficient to allow shallow draft operation.

The shallow draft produces a lower drag and a higher speed for the same thrust than would be had for a corresponding

displacement hull. The reason for this effect is that the CAB ship drag is composed of two distinctly different type of forces. The drag resulting from skin friction on the immersed surface is directly proportional to velocity squared. The drag resulting from the friction of the bubble at the air-water interface is inversely proportional to velocity to the 1.566 power. Thus the sum of these two drag forces has a point at which an increase in speed actually results in a reduction in drag.

With the development of faster submarines and the spectacular increases in speed of aircraft the Navy is rightfully searching for a method of increasing the surface ship speed. A special project office, Surface Effects Ship Project Office (SESPO), has been created to specifically look into this problem and to evaluate proposals.

At the present time two 100-ton Captured Air Bubble vessels have been constructed. They are the Aerojet General 100-A and the Bell Aerospace Systems 100-B. These two craft are prototypes of a projected 2000 ton craft. Prior to construction of the 100-ton crafts, experimental models were constructed in the 3-ton range. One such craft, the XR-3 built by NSRDC, is presently being used in experiments at the Naval Postgraduate School. Additionally, Oceanics Incorporated was commissioned to develop a digital computer simulation of the CAB ship loads and motions. The program delivered to NPGS in October 1972, was a model of the 100-B.

B. OBJECTIVES

Development of the equations of motion for the CAB ship were made in terms of the various elements contributing separate forces to the different degrees of freedom. The objectives of the simulation given in reference 9 are here restated.

1. To provide a computerized form of six degree of freedom equations for SES craft that will yield time domain outputs of motions for the on-bubble mode of operation.

2. To determine the motions of specified, SES configurations with special references to human habitability, platform requirements (for military or commercial applications) and maneuvering requirements for the on-bubble mode of operation.

3. To establish a mathematical model for predicting maximum wave-induced bending moments, both longitudinal and transverse, on SES craft to provide techniques that would yield slamming responses for on-bubble mode of operation.

4. To determine the stability derivatives in the vertical plane from measured data of the vertical plane motions of existing SES craft in a random seaway.

The objective of this thesis is to closely examine and attempt to improve the mathematical model. Our method is one of revising and changing the 100-B model L&M program so that it accurately describes the motion of the XR-3 model test craft. Program conversion consists of subroutine modifications. In certain subroutines it was necessary only to

input to the program new data, based upon measured data from the test craft. In other subroutines the method of calculation, coefficients, or entire equations had to be revised. The thesis discusses thoroughly these changes and their corresponding rationale. In addition, a comparison of measured test craft data with the L&M program output for steady-state, calm water operating condition is used to establish the accuracy of the simulation.

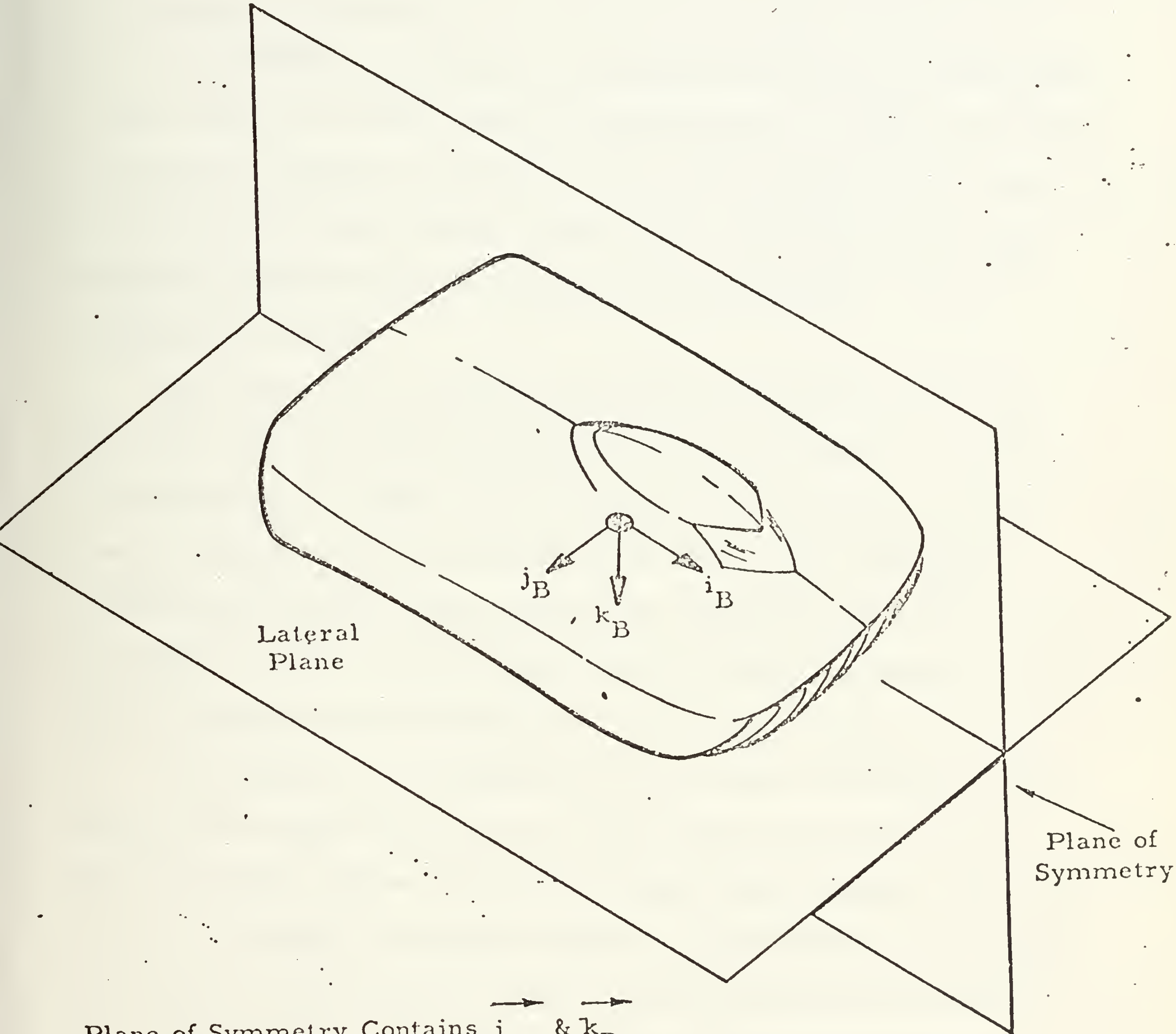
A users manual for this Fortran IV program is in Appendix A which includes descriptions of the subroutines and the method of inputting data. The program is designed to be operated in six degrees of freedom. Since many of the crafts parameters are input through the use of data cards a thorough reading of the subroutine descriptions and their corresponding inputs should be made before attempting to exercise this program as it presently exists.

II. EQUATIONS OF MOTION

INTRODUCTION

Motion of any vehicle which is free to move in a three dimensional space is made up of six degrees of freedom. That is, the vehicle (in this case the XR-3) may have translational motion in any one or more of three coordinate directions and it may also have rotational motion about any of these coordinate directions. In order to study these motions and the control problems of the XR-3, a mathematical model consisting of these six equations is required. These equations can then be used as the basis of a computer model suitable for simulation studies. In general, these above equations will be complex and nonlinear. The initial development and computerization of the six degree of freedom motion equations was based on the use of model test data, limited XR-3 test data, and theory for estimating the coefficients or constituent terms that appear in the equations. The inherent motion characteristics of the XR-3 are determined by exercizing this computer model. These results are compared with available test data and finally used to predict other motion characteristics not readily obtainable through XR-3 craft testing.

Early analyses of motions within the vertical and lateral planes were considered separately and revealed that linear equations provided an acceptable description of motions within the vertical plane (the symmetrical plane for the XR-3 as shown in Figure 1.). However, the linear lateral



Plane of Symmetry Contains $\vec{i}_B$ & $\vec{k}_B$

Lateral Plane Contains $\vec{i}_B$ & $\vec{j}_B$

Figure 1 SES Plane of Symmetry

plane equations proved to be inadequate and it was clear that nonlinear effects were significant in the description of asymmetric motions.

To produce a resultant functional form for the equations that will be the most simple form possible in order to achieve an ease of computer representation and solution while still including the main factors that affect craft motion, a simplified nonlinear representation was developed.

COORDINATE SYSTEM

The equations of motion describe the craft's movement in terms of an inertial reference frame in order to determine its position in space. Since the XR-3 is expected to have small angles of pitch and roll, the main angle indicating orientation of the ship relative to the inertial frame is the yaw angle. The range of this angle is large in order to properly describe craft turning motion in the horizontal plane.

A second set of coordinate axes, used to describe craft roll, pitch and heave, is the local level reference frame. The horizontal plane of this reference frame remains parallel to the horizontal inertial reference plane however its origin is placed at the craft's center of gravity above the mean free surface and its x-axis is in the craft's heading direction. The transformation between the local level and the inertial reference planes is given by

$$\begin{vmatrix} \hat{i}_L \\ \hat{j}_L \\ \hat{k}_L \end{vmatrix} = \begin{vmatrix} \cos\Psi, & \sin\Psi, & 0 \\ -\sin\Psi, & \cos\Psi, & 0 \\ 0, & 0, & 1 \end{vmatrix} \begin{vmatrix} \hat{i}_I \\ \hat{j}_I \\ \hat{k}_I \end{vmatrix}$$

The craft's heave, pitch, and roll motions are related to the local level reference plane through a third set of coordinate axes called the Body Frame. The Body Frame, also called the ship axis system, has its origin at the ship's center of gravity and its positive x-axis is also aligned in the direction of the ship's bow, the y-axis is positive to starboard, and the z-axis is positive downward. The transformation between the body axes and the local level axes is given by

$$\begin{vmatrix} \hat{i}_B \\ \hat{j}_B \\ \hat{k}_B \end{vmatrix} = \begin{vmatrix} A_{xx} & A_{xy} & A_{xz} \\ A_{yx} & A_{yy} & A_{yz} \\ A_{zx} & A_{zy} & A_{zz} \end{vmatrix} \begin{vmatrix} \hat{i}_L \\ \hat{j}_L \\ \hat{k}_L \end{vmatrix}$$

where:

$$\begin{aligned} A_{xx} &= \cos\theta \\ A_{xy} &= o \\ A_{xz} &= -\sin\theta \\ A_{yx} &= \sin\emptyset\sin\theta \\ A_{yy} &= \cos\emptyset \\ A_{yz} &= \sin\emptyset\cos\theta \\ A_{zx} &= \cos\emptyset\sin\theta \\ A_{zy} &= -\sin\emptyset \\ A_{zz} &= \cos\emptyset\cos\theta \end{aligned}$$

Finally, to describe the orientation of the fixed body frame with respect to the inertial frame a set of single axis rotations are performed. These rotations, through what are known as Euler Angles, bring the inertial frame into

alignment with the body frame. Taking the sequence to be positive rotations about the $\hat{k}$, $\hat{j}$ and $\hat{i}$ axes, in that order, the corresponding rotations are Ψ (yaw), θ (pitch), and $\emptyset$ (roll), and the transformation between reference frames is given in terms of these Euler angles by:

$$\begin{vmatrix} \hat{i}_B \\ \hat{j}_B \\ \hat{k}_B \end{vmatrix} = \begin{vmatrix} B_{xx} & B_{xy} & B_{xz} \\ B_{yx} & B_{yy} & B_{yz} \\ B_{zx} & B_{zy} & B_{zz} \end{vmatrix} \begin{vmatrix} \hat{i}_I \\ \hat{j}_I \\ \hat{k}_I \end{vmatrix}$$

where:

$$B_{xx} = \cos\theta\cos\Psi$$
$$B_{xy} = \cos\theta\sin\Psi$$
$$B_{xz} = \sin\theta$$
$$B_{yx} = \sin\emptyset\sin\theta\cos\Psi - \cos\emptyset\sin\Psi$$
$$B_{yy} = \sin\emptyset\sin\theta\sin\Psi + \cos\emptyset\cos\Psi$$
$$B_{yz} = \sin\emptyset\cos\theta$$
$$B_{zx} = \cos\emptyset\sin\theta\cos\Psi + \sin\emptyset\sin\Psi$$
$$B_{zy} = \cos\emptyset\sin\theta\sin\Psi - \sin\emptyset\cos\Psi$$
$$B_{zz} = \cos\emptyset\cos\theta$$

Figure 2 illustrates the relative orientation of the above mentioned reference frames.

During normal operation of an SES vehicle, roll angle $\emptyset$ and pitch angle θ remain within a range where no great error is introduced by using linear approximations for the trigonometric functions. The resultant transformation between the inertial frame and the body frame now becomes:

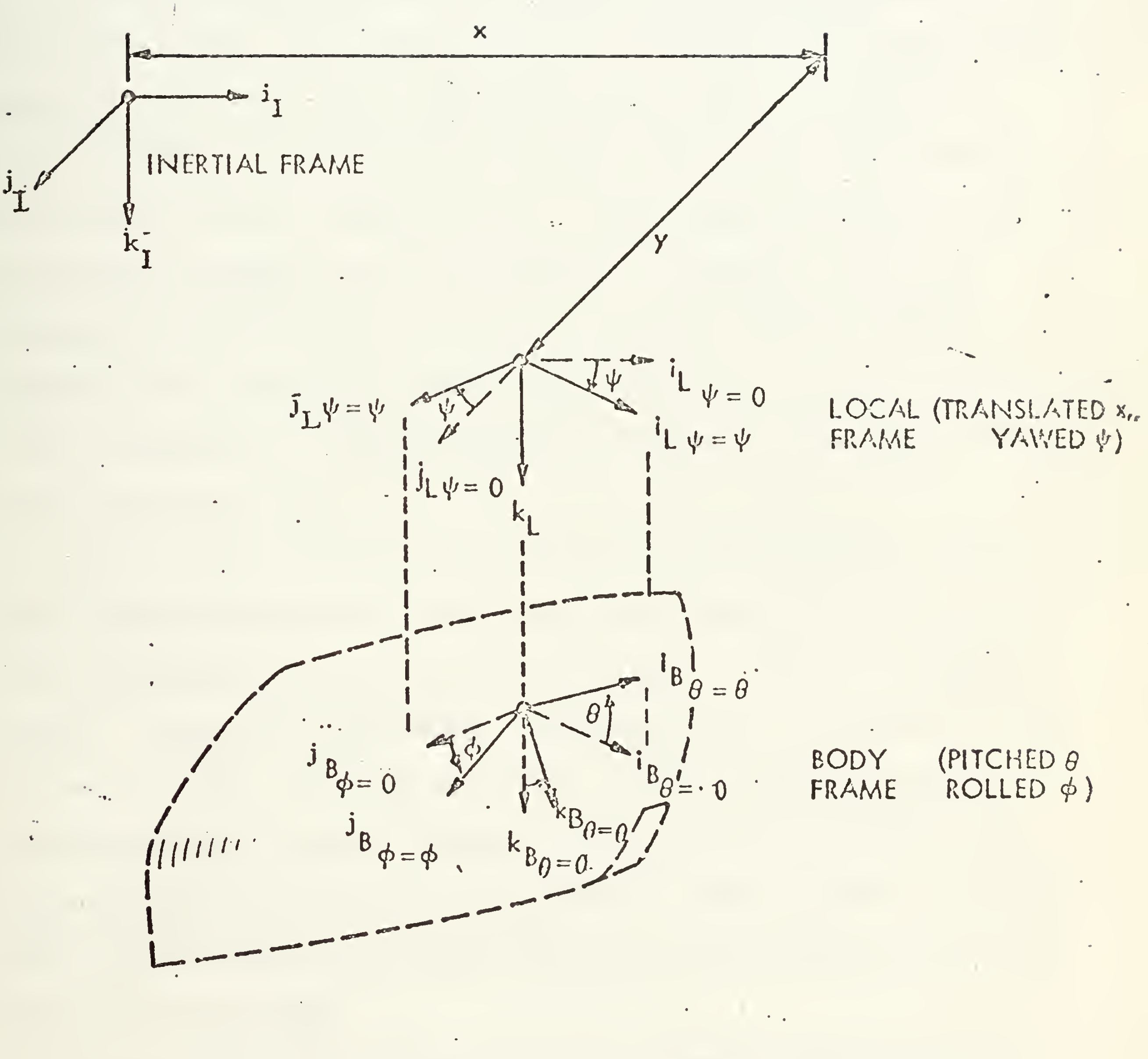


Figure 2 Relative Orientation of Reference Frames

$$\begin{vmatrix} \hat{i}_B \\ \hat{j}_B \\ \hat{k}_B \end{vmatrix} = \begin{vmatrix} \cos\Psi, & \sin\Psi, & -\theta \\ -\sin\Psi, & \cos\Psi, & \phi \\ \theta\cos\Psi + \phi\sin\Psi, & \theta\sin\Psi - \phi\cos\Psi, & 1 \end{vmatrix} \begin{vmatrix} \hat{i}_I \\ \hat{j}_I \\ \hat{k}_I \end{vmatrix}$$

DYNAMICS AND KINEMATICS

There are three general categories of forces acting on the XR-3 type craft. The first category of forces are those acting upon the hard structural elements of the ship (rigid body forces) such as the sidewalls, rudder, and deck. The second group of forces are those acting on the seals and transmitted to the ship through their attachments. Finally, the last category are those forces which act on the ship and water surface due to the air bubble and the lift fan system. Figure 3 is a simplified illustration of three force categories acting on an SES type craft.

Craft motion occurs as a result of a combination of all three force categories. When the vector sum of all these forces are in balance, the craft will continue in a state of uniform motion. Motions in the plane of symmetry are: forward and aft motion or surge; vertical motion or heave; and pitch motion or rotation in the vertical plane. Motions in the lateral plane are; sway motion or lateral translation; yaw motion a rotation about the vertical axis; and roll motion or rotation about the forward and aft axis.

The craft will accelerate in the forward direction as a result of propulsive thrust at some equilibrium velocity. The pitch motions of the craft are determined by the interactions between thrust, drag, lift and gravitational forces. Heave

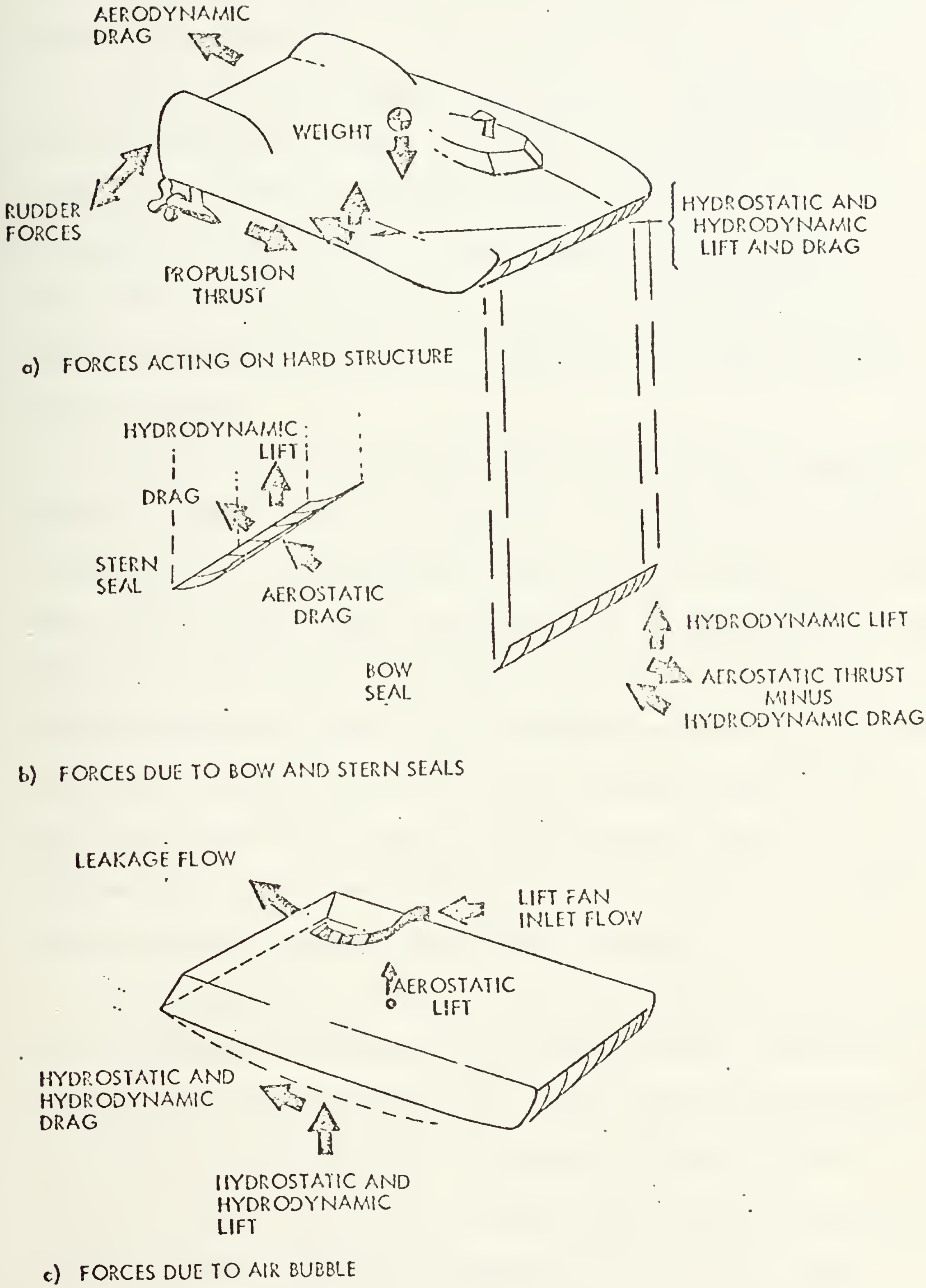


Figure 3. Static Forces Acting on a Surface Effect Ship

motions result from variations in bubble pressure, buoyant forces on seals, sidewalls, and waves reacting against the weight of the craft.

Motions in the lateral plane result from sideforces acting through the center of gravity to produce lateral translation or sway, sideforce offset longetudinally from the center of gravity to produce angular yawing motion, and lift force offset laterally as well as sideforce offset vertically from the center of gravity to produce angular rolling motion.

In order to describe the above motions in a simple and accurate manner which is conducive to computer programming, a correct choice of kinematic variables and coordinate systems must be made. When the equations of motion have been solved for that set of variables, all other variables can then be evaluated using the relationships between kinematic variables; and when the orientation of the body frame has been established, all other vectors however expressed can be resolved into any common frame using the previously given transformations between coordinate systems.

The equations of motion have been based on the following chosen kinematic variables: the Euler angle, and their time derivatives: ψ,θ,ϕ; $\dot{\psi},\dot{\theta},\dot{\phi}$; $\ddot{\psi}$, $\ddot{\theta},\ddot{\phi}$; and the components of the velocity of the origin of the body frame, resolved in the direction of the local level frame axes; and the time derivatives of these velocity components, u_L, v_L, w_L, and $\dot{u}_L$, $\dot{v}_L$, $\dot{w}_L$, where u_L is the component in the $\hat{i}_L$ direction,

v_L is in the $\hat{j}_L$ direction, and w_L is in the $\hat{k}_L$ direction. The equations of motion are to be solved for

$\ddot{\psi}$, $\ddot{\theta}$, $\ddot{\phi}$, $\dot{u}_L$, $\dot{v}_L$, $\dot{w}_L$.

Two advantages to this coice of variables and reference frames are; first, the simplicity in the integrations required to determine the orientation of the body frame and the location of its origin, and second, is that it facilitates a reduction of degrees of freedom. That is, the equation for $\ddot{Z}$ can be easily reduced to obtain a representation of the heave-only mode which is a readily interpretable motion.

One inescapable disadvantage to the above choice is that the transformations required to resolve components into local level frame axes and to express relationships in terms of selected kinematic variables are nonlinear. In most cases this process has been simplified by using only the first order terms in the Euler angles. It is to be noted that, in comparison to the bubble lift force, the other forces acting on the craft are generally small; hence, first order transformations from body frame to local level frame axes actually provide representative second order accuracy.

As previously stated a net unbalance of forces or moments along or about any axis will cause the craft to accelerate along or about that axis. This acceleration is called a kinetic reaction. This principle known as D'Alemdert's principle can be more formally stated that when the kinetic

reaction contributions are included, the sum of all forces and moments vanish. Stated mathematically we have:

$$0 = X - \sum_i F_i \hat{i}$$

$$0 = Y - \sum_i F_i \hat{j}$$

$$0 = Z - \sum_i F_i \hat{k}$$

$$0 = K - \sum_i M_i \hat{i}$$

$$0 = M - \sum_i M_i \hat{j}$$

$$0 = N - \sum_i M_i \hat{k}$$

where X,Y and Z are the kinetic reactions and $F_i \hat{i}$, $F_i \hat{j}$, and $F_i \hat{k}$ and $M_i \hat{i}$, $M_i \hat{j}$, and $M_i \hat{k}$ are the various forces and moments due to thrust, drag, gravity, bubble pressure, and buoyancy in the X,Y and Z directions of the local level reference frames.

To evaluate the kinetic reactions it is assumed that the moments of inertia of the craft are constant with respect to the local level coordinate system. Now, the direct application of Newton's laws of motion for a rigid body relative to this coordinate system leads to the following equations of motion or kinetic reactions:

$$m \; (\dot{u} - v\dot{\psi}) = X$$

$$m \; (\dot{v} + u\dot{\psi}) = Y$$

$$m \; \dot{w} = Z$$

$$I_{xx} \ddot{\phi} - I_{xz}\ddot{\psi} - I_{yy}\dot{\psi}\dot{\theta} = K$$

$$I_{yy} \ddot{\theta} - I_{xz} \; (\dot{\psi})^2 + I_{xx} = M$$

$$I_{zz} \ddot{\psi} - I_{xz} \ddot{\phi} = N$$

Computations using analog computers have revealed that the nonlinear inertial coupling terms included in the above equations contributed only negligible differences to the responses of expected forcing functions (see reference 9). Hence, the decision was made to simplify the equations of motions to be used by deleting all nonlinear inertial coupling terms. The resulting equations are then given by:

$$m\dot{u} = X$$

$$m\dot{v} = Y - mu\dot{\Psi}$$

$$m\dot{w} = Z$$

$$I_{xx}\ddot{\phi} - I_{xz}\ddot{\Psi} = K$$

$$I_{yy}\ddot{\theta} = M$$

$$I_{zz}\ddot{\Psi} - I_{xz}\ddot{\phi} = N$$

Note: The $u\dot{\Psi}$ product is retained since it is not a small quantity.

The above simplified equations can be represented in matrix form by:

$$\begin{vmatrix} m & 0 & 0 & 0 & 0 & 0 \\ 0 & m & 0 & 0 & 0 & 0 \\ 0 & 0 & m & 0 & 0 & 0 \\ 0 & 0 & 0 & I_{xx} & 0 & -I_{xz} \\ 0 & 0 & 0 & 0 & I_{yy} & 0 \\ 0 & 0 & 0 & -I_{xz} & 0 & I_{zz} \end{vmatrix} \begin{vmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \\ \ddot{\phi} \\ \ddot{\theta} \\ \ddot{\Psi} \end{vmatrix} = \begin{vmatrix} X \\ Y - mu\dot{\Psi} \\ Z \\ K \\ M \\ N \end{vmatrix}$$

This matrix representation is used to establish a procedure by which the digital computer solves the equations of motion.

Detailed descriptions of the component forces and moments which contribute to the motion of the XR-3 craft are provided in the subroutine descriptions that follow this section.

III. PROGRAM SUBROUTINE MODIFICATIONS

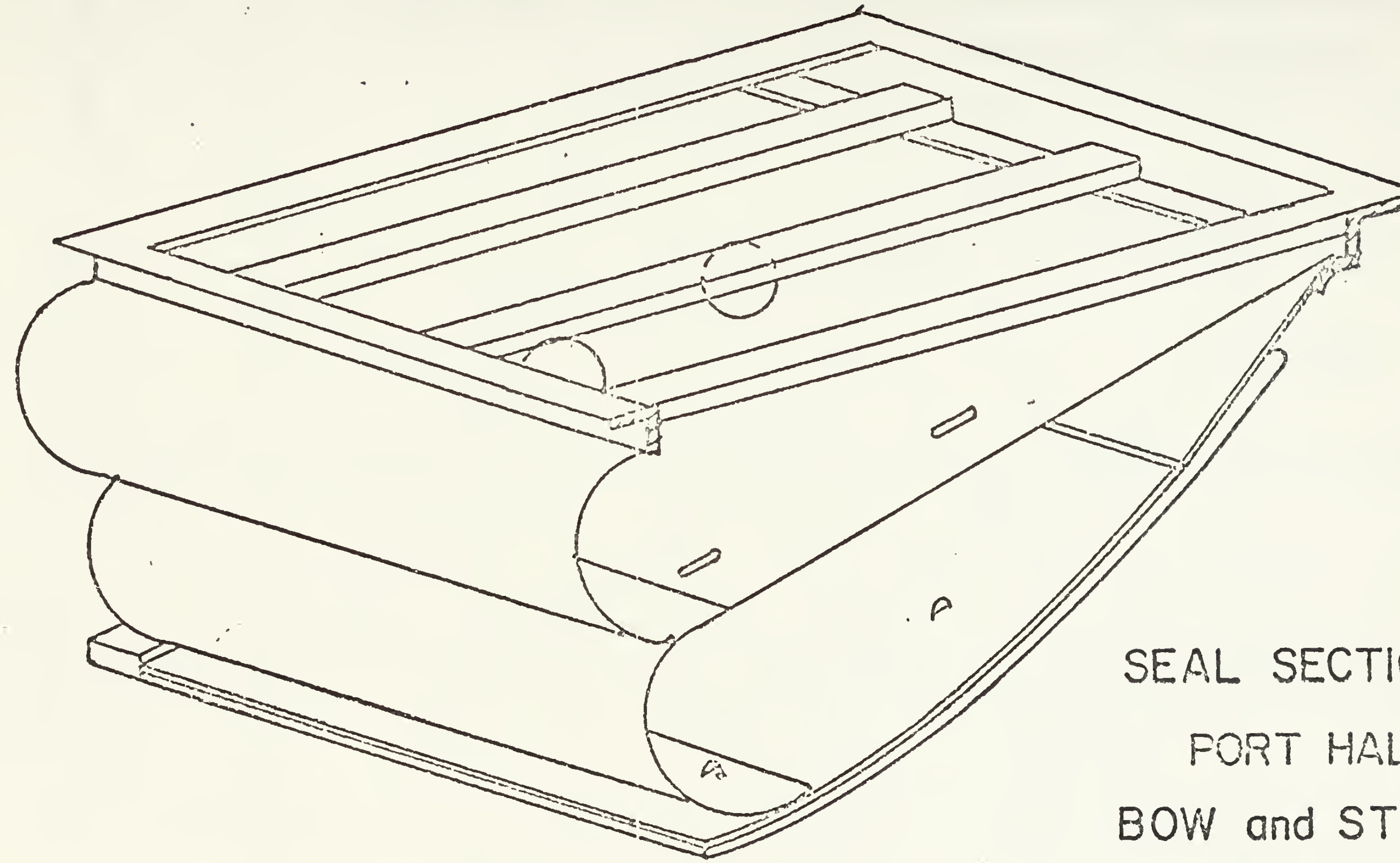
A. MAIN

The only changes to the main portion of the program was the introduction of the term VEL and the corresponding format change so that velocity is written in knots instead of feet per second.

B. SUBROUTINE BOW SEAL

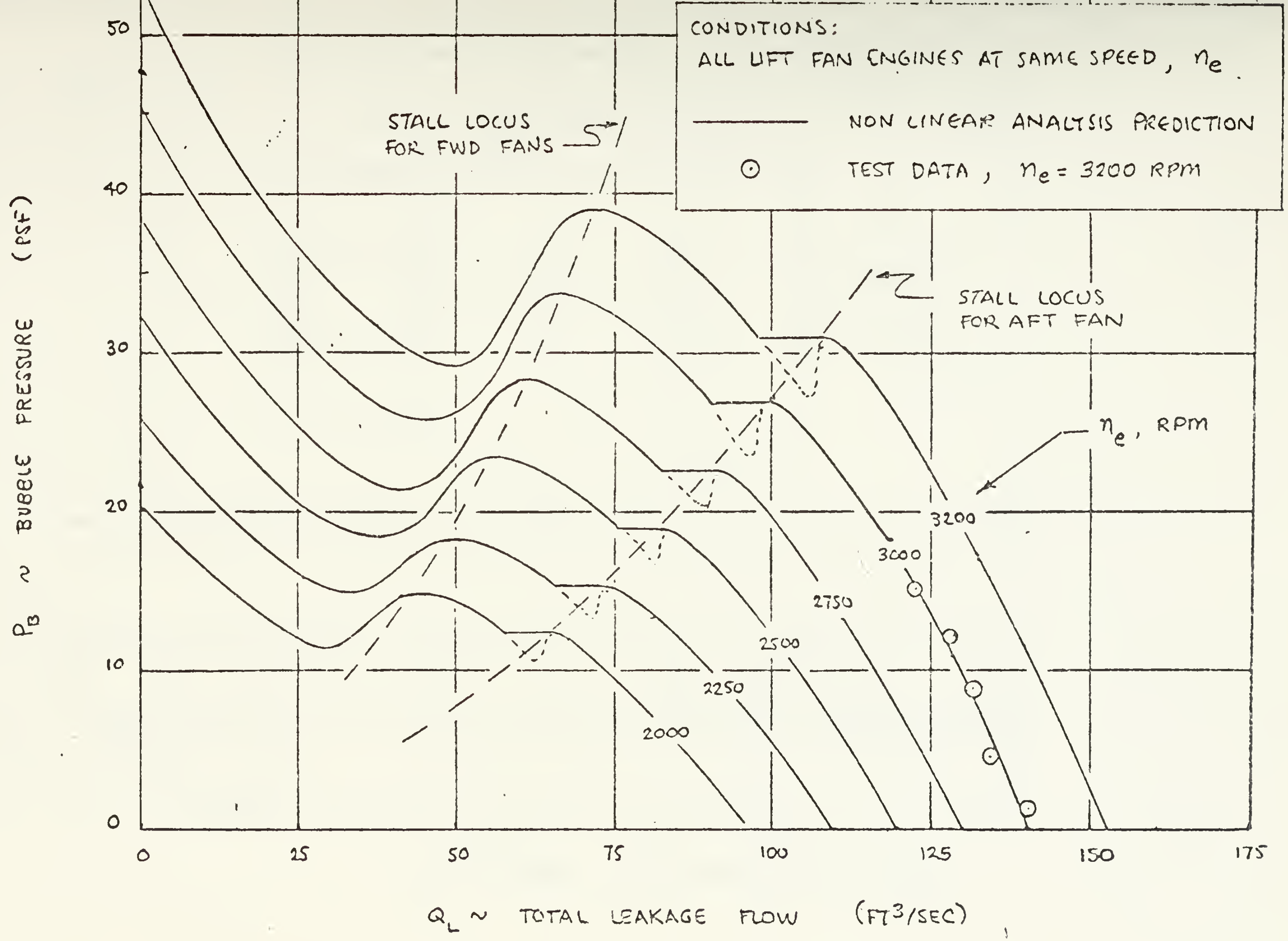
The XR-3 is presently equipped with soft air-spring type bow and stern seals. These seals were designed and constructed by NSRDC and installed by NPGS. The seals illustrated in Figure 4 are double-celled air bags consisting of a 46" X 120" frame and fabric ends, sides, and bottom. Twelve equally spaced steel spring stiffeners reinforce the bottom of the seals. The divider membrane has holes in it which serve as a damping device. Winches and cables have been attached to the rings shown in Figure 4, so that the shape of the inflated seal may be changed.

To inflate the seals ducted fans are used. The characteristics of these fans are shown in Figure 5 and the ducting arrangement in Figure 6. As can be seen from Figures 5 and 6, two ducted fans supply air to the bow seal. The rate of flow is 125 cubic feet per second per fan; hence, the total flow to the bow seal is 250 cubic feet per second. The return ducting, shown in Figure 6, allows the vane axial fans to deliver flow and not cause the seal to inflate like a balloon. There is sufficient fan flow to produce a pressure



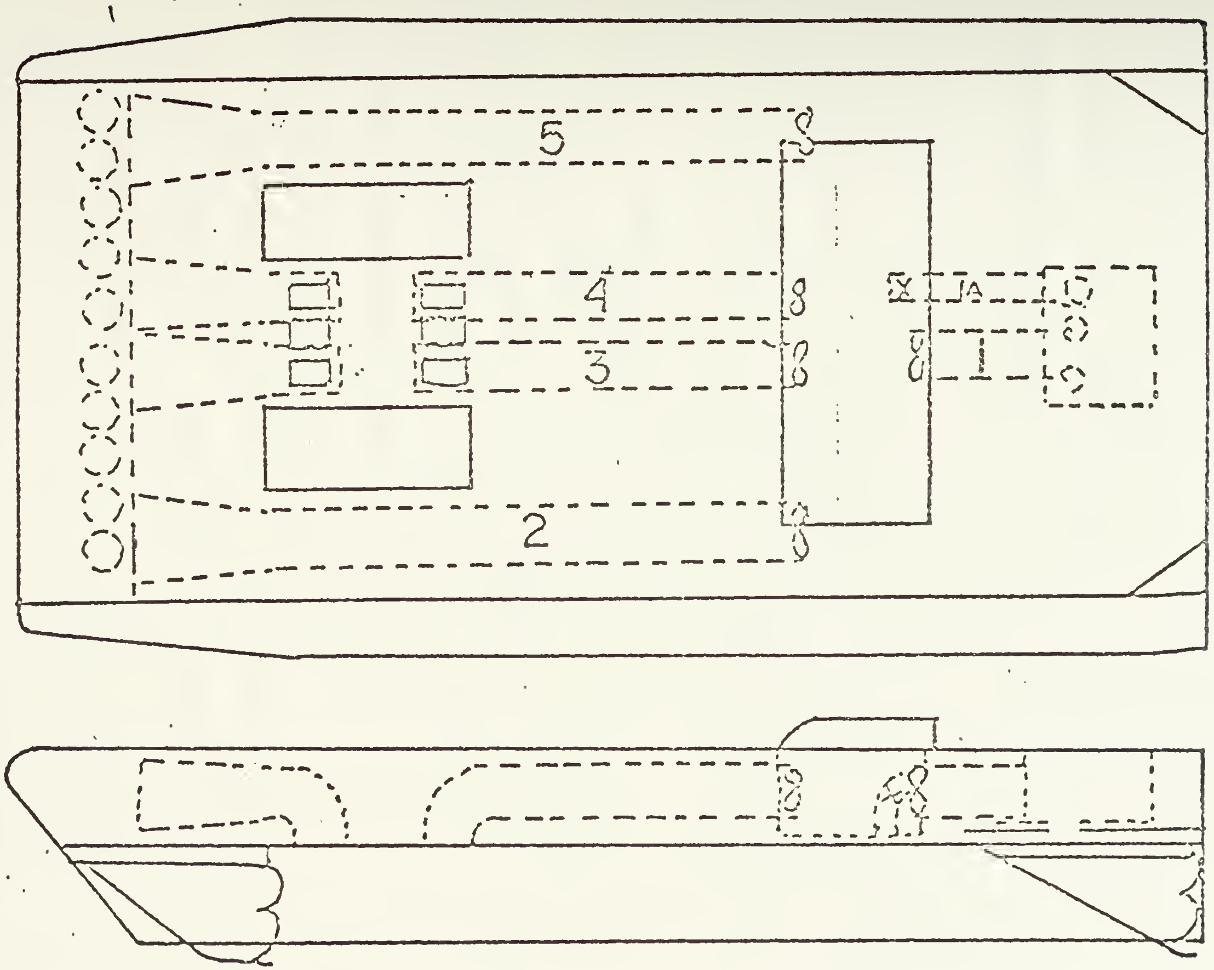
SEAL SECTION
PORT HALF
BOW and STERN

Figure 4



FAN FLOW CHARACTERISTICS

Figure 5



DUCTING CONFIGURATION

Figure 6

differential between the seals and the plenum chamber of about 1 to 2 psf. depending on the plenum pressure.

The stern seal of the 100B is of similar construction to the bow seal presently installed in the XR-3 and therefore the 100B Stern Seal Subroutine was used as the basis for computer representation. By comparison of Figures 4 and 7, the XR-3 seal configuration and the 100B stern seal configuration respectively, we can note strong similarities. Both are of pressurized fabric-type material that is assumed to have no inertia or dynamics and are constructed with a vented membrane separating the lobed air bags. The throttle shown in Figure 7 is merely a controllable path for the air to return to the plenum. This throttle corresponds to the return ducting previously mentioned.

The process of modification of the program involved the identification of the elements of the 100B stern seal calculations so that proper subsititutions could be made without destroying the continuity as well as the way in which the program coupled with itself.

The first computation considered was the calculation of the bow seal gap. GAP is here defined as that space resulting from lifting the seal beyond the surface of the water, that is, an air gap resulting in a loss of air from the plenum and increased air flow. The equation is here reproduced without its iterative subscripts.

SES 100 STERN SEAL

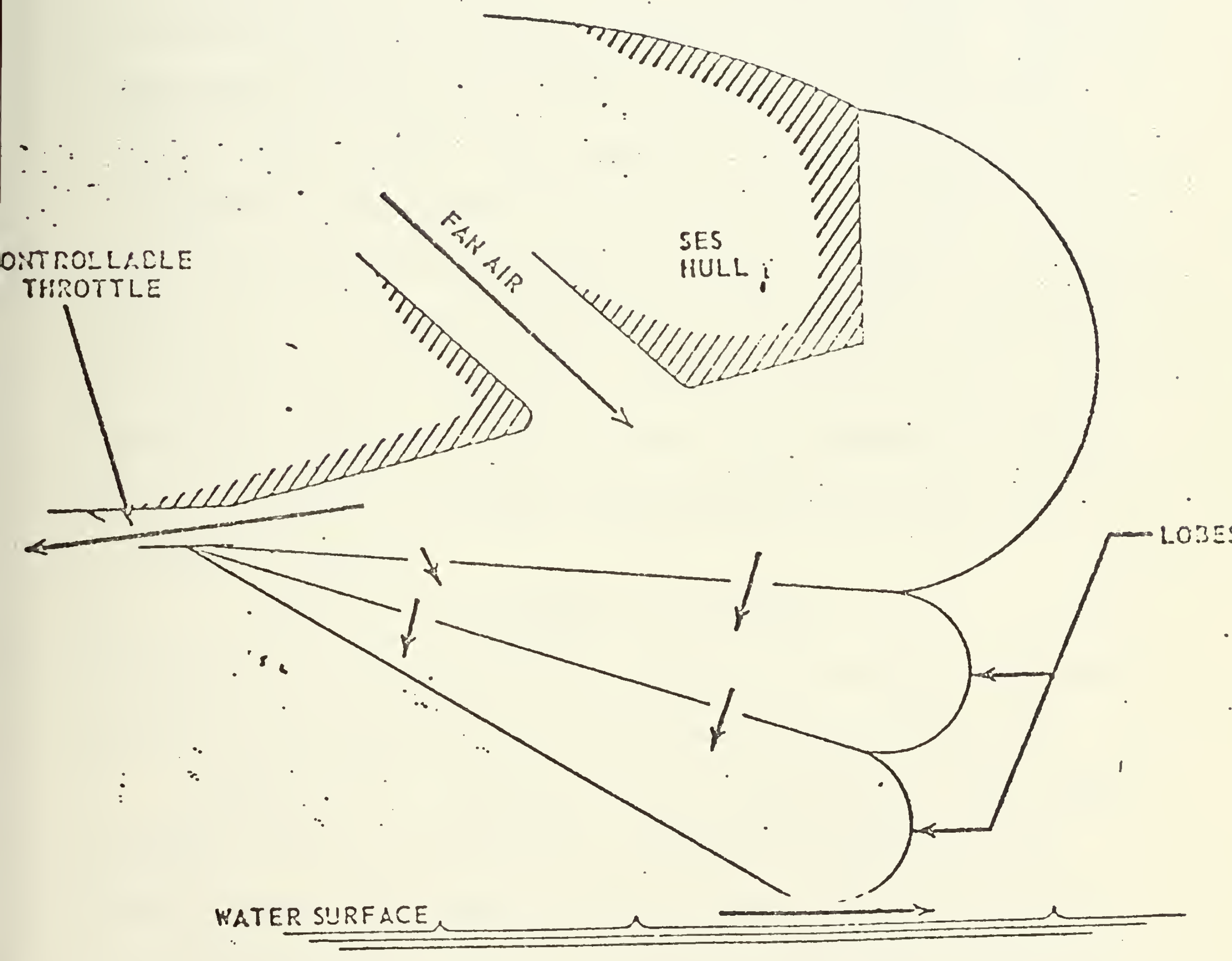


Figure. 7

```
GAP = -(Z+ZS-XX(3,K)*THETA+YY(3,K)*PHI+ETA(3,K))
XX(3,K) = XBS+RBS*COS(ANG)
YY(3,K) = RBS*SIN(ANG)
```

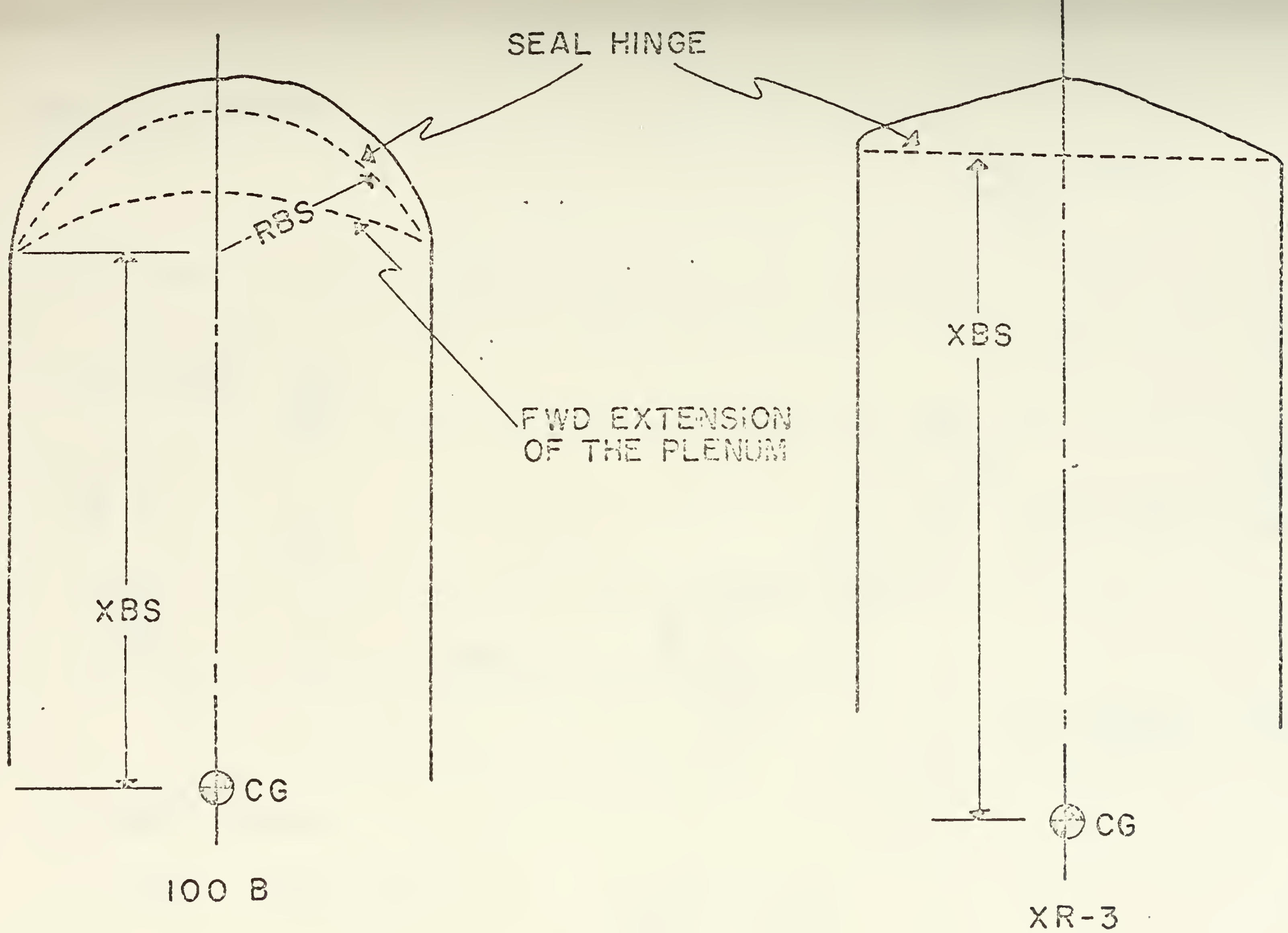
This calculation results in the distance DS as shown in Figure 9.

The purpose of the XX(3,K) and YY(3,K) calculations are to locate points along the perimeter of the hinge. The distances XBS, XX(3,K) and YY(3,K) can all be found in Subroutine INCON. RBS is not required for the XR-3 seal and is removed. The reason for the calculation of RBS was that the 100B hinge is semicircular in shape as shown in Figure 8. The XR-3, on the other hand, has a seal that has its hinge on the bow of the ship and is affixed straight across, athwartships, therefore XX(3,J) = XBS. The distance, YY(3,J) is an incremental distance athwartships and is also calculated in INCON.

```
YY(3,J) = 0.5*XBBW+(J-1)*DELYBS
```

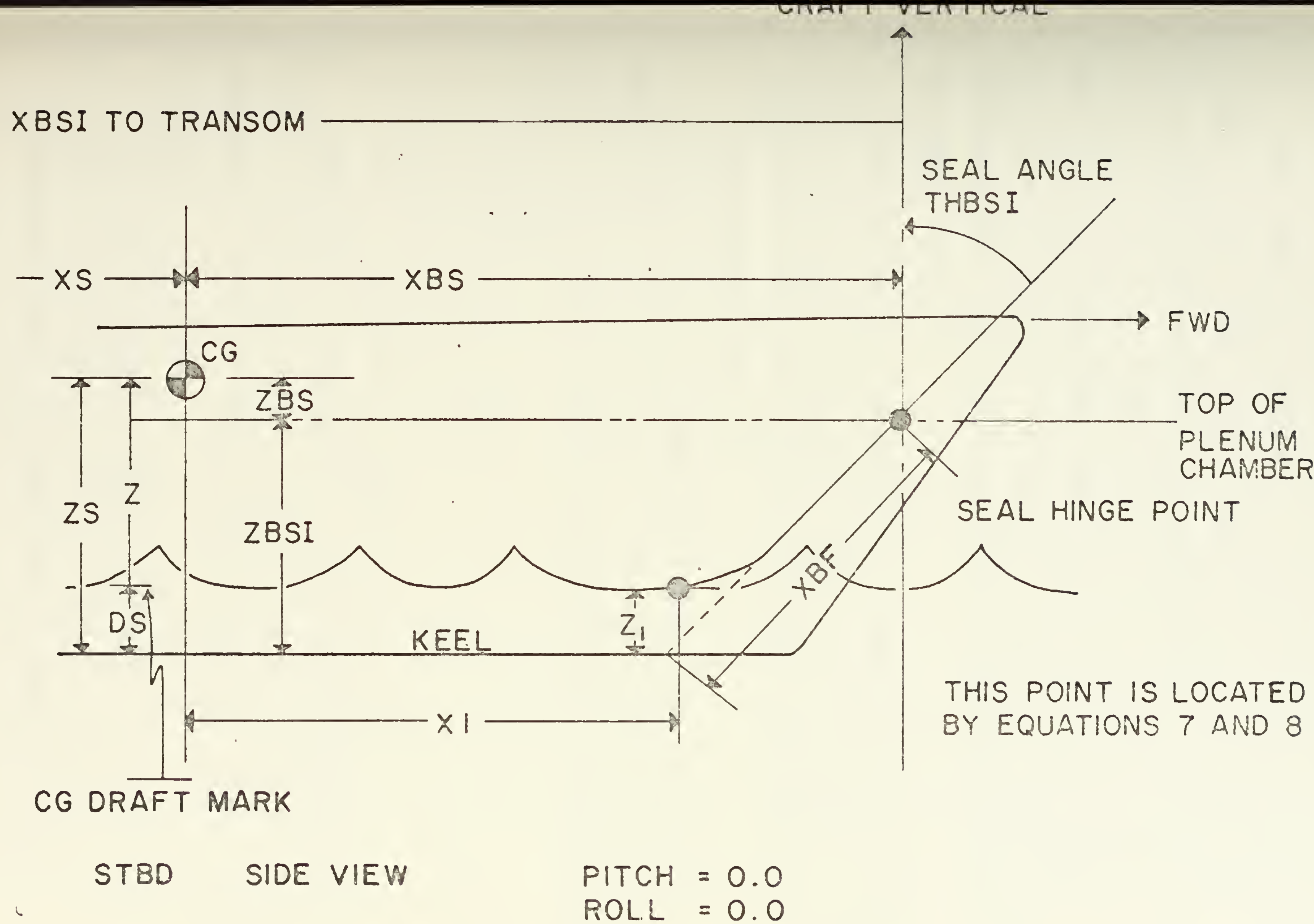
In this way we have located a series of straight line segments running athwartships at the seal hinge location.

Initially the overhang of the bag portion of the 100B bowseal had been calculated as ELBAG by Subroutine FG1. Since the XR-3 bow seal has no overhang, this calculation has been removed. The bow and stern seal of the XR-3 are basically alike and therefore the only differences are in the definition of terms used in the equations. The corresponding changes have been made in INCON, RUDDER, RHS, and wherever else the Common Block ties were made. New



BOW SEAL HINGE ARRANGEMENTS

Figure 8



BOW SEAL CONFIGURATION

Figure 9

terms that were included match their corresponding terms in the 100B Stern Seal Subroutine. With reference to Figure 9, these are XBF which is the length of the seal from hinge to transom, THBSI which is the angle between the craft vertical and the seal, BLEAK which is the seal base leakage area, ZBS which is the distance from the CG to the seal hinge, COSBS and SINBS, which correspond to SINTH and COSTH in the 100B program. These later two terms are the SIN and COS of the THBSI bow seal.

The following is an equation by equation discussion of the XR-3 Bow Seal Subroutine. The first few statements serve to zero the force, GAP vector, SKI vector and leakage area.

(1) DELPBG = PBS - PB

Equation (1) calculates the differential in pressure between the bubble (plenum) PB, and the bow seal bags, PBS. PB is calcualted in Subroutine RHS and PBS is an INCON Subroutine input.

(2) PBAR = PB - PINF

(3) DELP = PBAR

(4) IF (DELP.LT.0.0.) DELP = 0.0

Equations (2) through (4) calculate the pressure difference between the bubble, PB, and the sea level value PINF, insuring that DELP is never negative since we cannot create a vacuum in the plenum.

(5) SINDIF = SINBS - COSBS * THETA

(6) COSDIF = COSBS - SINBS * THETA

COSBS and SINBS are calculated in Subroutine INCON.

THETA is the pitch angle and is considered small enough to use the small angle approximation for the sin. Therefore, equations (5) and (6) represent adjustments to the INCON values, COSBS and SINBS, due to pitch angle.

(7) X1 $\doteq$ XBS+ZBS*THETA-XBF*SINDIF

(8) Z1 = -Z-ZBS+XBS*THETA-XBF*COSDIF

Equations (7) and (8) locate a line on the water's surface of the seal based upon the draft and pitch angle. Referencing Figure 9 which assumes no pitch or roll it can be seen that the distance determined by equation (7) is indeed X1. Similarly we see that equation (8) locates the distance Z1. It is assumed that the forces acting upon the seal and the craft act along this line which is centered in the wetted area at the water's surface. The assumption is that the seal, being a buoyant body does not penetrate sufficiently the water's surface, but floats upon it.

The next task is to calculate the wetted area of the seal and the gap, if any. The seal may be divided into as many as eleven segments according to NSTA(3).

(9) ELSKI (K) = (ETA(3,K)-DETABX(K))*(XX(3,K)-X1)-Z1+ W(3,K)*PHI

(10) GAP(K) = ELSKI(K)

(11) IF (GAP(K).LT.0.0) GAP(K)=0.0

ELSKI represents the wetted length of the small segment corrected for waves, (ETA(3,K)-DETABX(K)): and roll, PHI. Equation (11) provides that as long as ELSKI is negative no gap exists. Equation (12) computes an average of ELSKI over the segments previously determined.

(12) ELSKIA = (ELSKI(J+1)+ELSKIA(J))/2.0

Obviously if the average wetted length computes to be less than zero there is no need to make any of the following computations and gap is the only meaningful term. However, as is usually the case, ELSKIA has a value and it is then necessary to next test ELSKIA and determine if it exceeds the maximum wetted length permissable. If so, it is then set to the maximum value. This is reasonable since the maximum wetted area would exist when the top of the plenum was contacted by the water and the computations would stop. The succeeding equations calculate a coefficient of drag based upon the craft velocity and then the resulting drag forces. Similarly the remaining forces and moments are calculated.

The leakage flow, QL, was not permitted in the 100B unless the seal broached the surface and GAP became non-zero. In the case of the XR-3 it was found that there existed a leakage area between the sidewalls and the bow seal itself. This gap was calculated and input as CFBS in Block 6 of Subroutine INCON. This small area accounts for a flow of approximately 10 cubic feet per second.

Inputs to Subroutine BOWSL will be discussed in the section covering Subroutine INCON.

C. SUBROUTINE COLFIL

The Colfil Subroutine controls output, both form and content. Since substantial changes to the Oceanics L&M

program have been made, a user's manual for this subroutine is included in Appendix A. The modifications herein described were made for the purpose of arranging the output in a more convenient form for the purposes of this report. Presently time histories of 16 variables may be printed in two tabled summaries of values and up to 10 graphs plotted in each run. Additional variables may be output by a single change to the present format. The graphs may be drawn on either the off-line (calcomp) or on-line (print) plot. Changing this routine necessitated minor changes in both the RHS and INCON Subroutines.

The changes in RHS consisted of modifying the method of writing the variables on the temporary storage device. Only one temporary storage device is used. This was done in order that the list can be searched by variable number instead of searching by variable name.

The changes in INCON necessitated the creation of new blocks 20,21, and 22. Information input and the form of that information can be found in the user's manual, Appendix A.

D. SUBROUTINE INCON

The INCON Subroutine is the most difficult of all the subroutines to discuss since it reads and computes the initial conditions of all variables and constants which affects how the entire program functions. The thorough understanding of this subroutines' function and operation are a prerequisite

to exercising the program. To assist in this understanding a description of the operation of the Subroutine and where necessary full description of the important functional computations is presented in this section.

The INCON Subroutine is divided into numbered blocks which are controlled by the read statement number 10. (see Appendix B). Notice that the method is to read a 3 digit integer followed by a 2 digit integer. The first 3 digits are called the block number and the next 2 digits the option tag. By executing the computed go to statement according to the block number the statement next executed can be controlled. Consider as an example the number 01601. The block number is 016 and the option tag is 01. Hence, the block number will cause the program to flow to statement number 1600 by the GO TO control and then be routed to statement 1605 by option tag number in another GO TO control. Using this flow control all of the necessary information is input to the program from the card reader and disk.

What follows is not a bock by block description of the input, but rather a description of those places in which changes have been made and in which particular calculations of interest occur. A block by block explanation of the input is contained in the user's manual Appendix A.

Block 2 option 1

This input block is the summary mass and inertia input. Option 2 allows a discrete mass input to be read. It is important to point out the source of the numbers presently

being used for the XR-3. As a first approximation the moments of inertia found on page 1 of reference 2 were scaled up to the present XR-3 configuration. The craft weight given in reference 2 was 4192 pounds and a ratio of $\frac{5813}{4192} = 1.39$ was used to compute the following inertias.

$IX = 2941$ slug ft^2

$IY = 9320$ slug ft^2

$IZ = 11300$ slug ft^2

However, the numbers presently employed are those provided by NSRDC and are:

$IX = 2870$ slug ft^2

$IY = 9320$ slug ft^2

$IZ = 10580$ slug ft^2

As can be seen, the difference is minimal. No information was available for the product inertia I_{XZ} and therefore it was assumed to be zero value.

Block 4 option 2

The appendages section of the program has been removed since there are no fins or other appendages on the XR-3.

Block 5

The measured data inputs to the stern seal block consists of the X and Z coordinate of the seal hinge, the seal angle, the length of the seal leading edge, the pressure differential between the seal bag and the plenum chamber, seal leakage orifice coefffficient and the base leakage area.

It was assumed that the leakage orifice of the XR-3 had the same characteristics as the stern seal orifice of the

100B. Thus the seal leakage orifice coefficient remains unchanged.

The base leakage area refers to that area over which the leakage coefficient exerts influence. This is the gap that allows a flow from the plenum to the atmosphere. The leakage flow is the control over the plenum pressure, fan flow rate and thence the fan horsepower calculations. The leakage area is distributed throughout the craft and it is necessary that this number be adjusted to bring the above three calculations into balance at a steady state operating condition. If the base leakage area is reduced it causes the craft to either rise, or the pressure to increase, or the fan flow rate to be reduced. The number presently being input is the result of such an adjustment and the three calculations are in agreement with experimental data concerning draft and plenum pressure.

Block 6

These bow seal inputs correspond to those of the stern seal in Block 5.

Block 7 option 2

The critical Froude Number was obtained as follows.

$$Fn \text{ critical} = \frac{V}{\sqrt{GL}} = \frac{13.4}{\sqrt{(20)(32)}} = .556$$

Where: V = speed in feet per second (critical or hump speed)

L = length of the plenum (nominal) in feet

G = gravitation constant

Block 8 option 1

Those inputs that correspond to thrust have been removed and are found in block 16.

Block 9 option 1

Although there is no rudder on the XR-3, it was considered necessary to provide information for the rudder effect produced by the propulsion system. Refer to Figure 10 which shows a crossectional view of one of the outboard motors. Dimensions in the figure are inches and must be converted to feet and square feet for input.

The first assumption made was that the effect of the outboard motors could be separated into two parts, first, the forces contributed only by rudder action and secondly the forces which result from the thrust.

The second assumption was that the dashed line represents the water surface under most operating conditions. That is, at the stern, the water level doesn't change much; at least, not enough to reflect great rudder force changes. Additionally, waves do not interrupt flow at the rudder. Therefore, all that is required is to determine the respective areas and lengths, convert them to feet and enter them properly through the card reader. The wetted surface rudder effect area, therefore, is that region which is cross hatched in Figure 10.

Rudder span is defined as the vertical length of the rudder. This distance is the wetted surface distance. Based upon the foregoing assumptions only 2/3 of the block marked

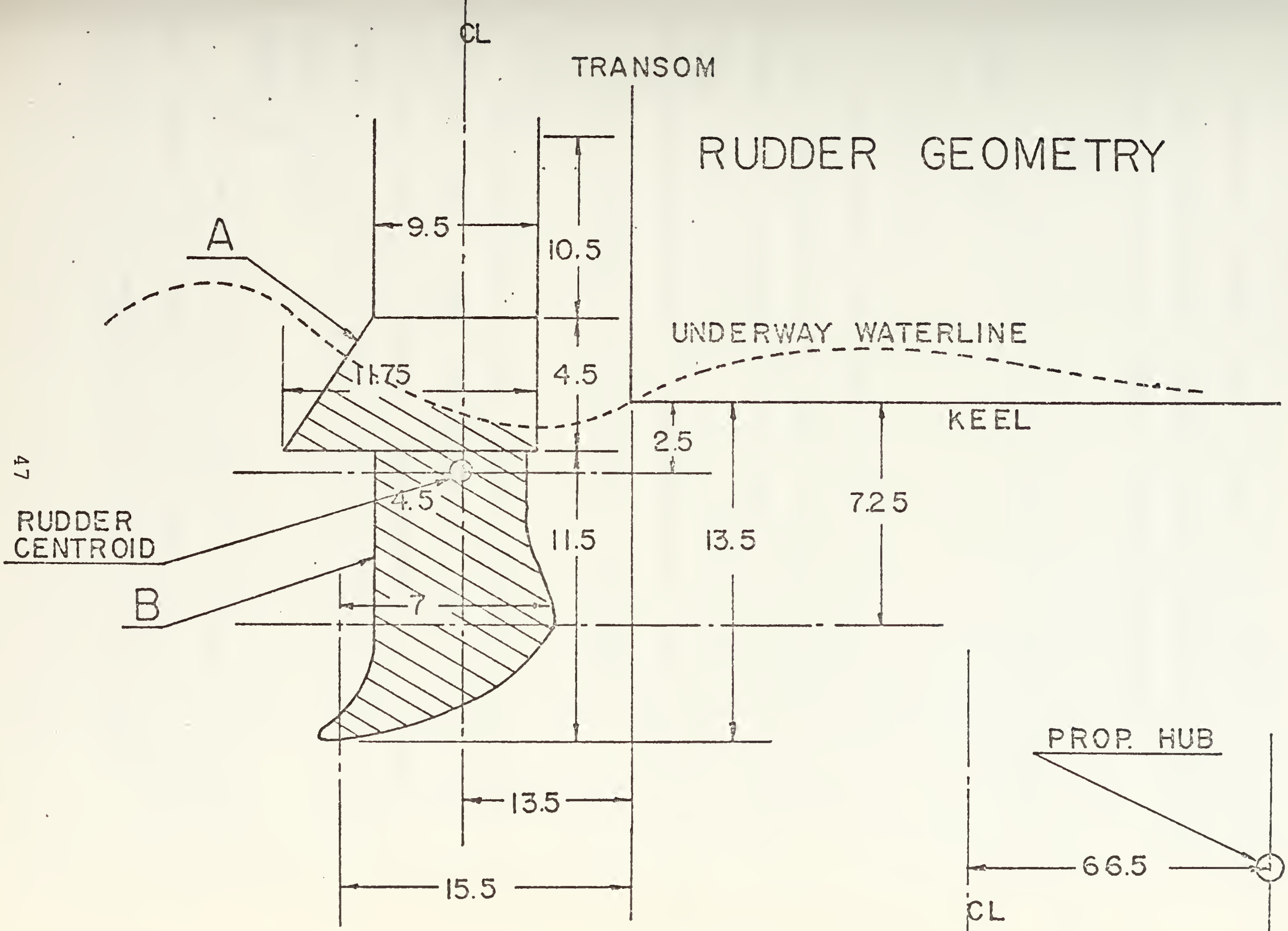

RUDDER GEOMETRY
TRANSOM
CL
A
9.5
10.5
4.5
11.75
UNDERWAY WATERLINE
KEEL
2.5
4.5
7.25
RUDDER CENTROID
B
11.5
13.5
7
13.5
15.5
PROP. HUB
66.5
CL

Figure 10

A in Figure 10 through which the water line passes contributes to wetted area.

Therefore, rudder span = $\frac{2}{3}(4\frac{1}{2})+11\frac{1}{2}$ = 14.5" = (1.21 ft.).

The rudder aspect ratio is defined as the rudder span squared divided by the area, a dimensionless term.

$$\frac{(1.21)^2}{.68} = 2.15$$

Total rudder area is the summation of the cross-hatched area; A and B.

$$\frac{2}{3}A+B = R_A$$

The area of B is taken to be the average width 5.75 inces multiplied by the length. The area of Block A is taken to be a rectangle 11.75 inches by 4.5 inches with a small triangle removed. It is felt that these approximations will not lead to any gross force inaccuracies.

$$R_A = 31.9+66.1 = 98.0 \text{ inches}^2 \quad (.68 \text{ feet}^2)$$

Block 10

The aerodynamic inputs are the reference length and referenc width. These dimensions are used to compute a reference area to be used in conjunction with the particular values of the coefficients obtained from the wind tunnel tests.

Block 15

The shears and moments calculations have been removed and replaced by a dummy subroutine SAM, since no stress analysis will be performed on the XR-3. This removal

provides a convenience for the purposes of this report.

Block 16 option tag 1

Entries input in block 16 option tag 1 permit the user to input a predetermined time history of thrust on the starboard screw as a map. That is, either constant or variable thrust may be selected. The user must input data points from the map of the variable thruster and the function subprogram FG1 is used to determine the functional value of thrust at any given time. A maximum of 24 data points may be used to describe the map.

Block 16 option tag 2

Exactly the same as option tag 1, except that these entries apply to the port screw.

Block 16 option tag 3

The entries in block 16 option tag 3 allow the user to input a rudder motion map. Positive rudder angles are right rudder angles which cause the craft to turn to the right.

Block 17

Option tags 1 and 2 permit the user to vary bow and stern seal differential pressures as the program run progresses. The differential pressure is taken to be that between the seal and the plenum. This represents a revision to the original program.

Block 19 option tags 1,2, and 3

These inputs allow the user to input fan map data and thus control air flow in both the seals and plenum.

E. SUBROUTINE PROP

The forces and moments associated with the propulsion and steering systems for CAB craft are somewhat unique for each propeller and rudder system type. In the original Oceanics' program, written to simulate the Bell 100 ton SES, the system described consisted of two fixed super-cavitating propellers each with a rudder mounted directly astern. Both the propellers and rudders were located close to the transom of the craft. In the XR-3, the propulsion system consists of two forty horsepower outboard motors each is fitted with a two bladed screw. The port screw has a right hand rotation and the starboard has a left hand rotation. With this system steering is accomplished by rotating these motors in the horizontal plane. In turn, the main thrust vector produced by each propeller is rotated in the horizontal plane to provide a desired turning moment. Additional turning moment is provided by the motor/propeller housings which are essentially shaped like a rudder foil. However the surface areas of these housings are significantly reduced from typical rudder areas associated with a fixed propeller system. The rudder characteristics are further described in the RUDDER Subroutine.

The rotation of the propeller thrust vector in the horizontal plane adds a complication factor to the XR-3 description which was not present in the 100B craft simulation. Hence, the original PROP Subroutine required major changes in order to make it properly describe the XR-3 craft.

In the XR-3 description, as in the 100B, specific propeller characteristics such as; RPM, Blade pitch, and the various propeller coefficients are not included to determine the thrust and torque produced by each propeller. In both simulations the thrusts are either input values or calculated from the equations of motion for the associated input velocities.

The propeller representation allows either propeller to provide any desired thrust and side thrust independent of the opposite propeller. This feature is available through the use of function routine FG1. FG1 is used to describe the thrust of each propeller as a function of time. When the program operates in this mode the velocities and accelerations of the XR-3 are obtained from the equations of motion as a result of the input propeller thrusts. Another operating mode provides for velocity to be input and the resultant total propeller thrust is obtained from the motion equations. In this mode of operation, it is assumed that the total thrust is divided equally between both propellers, and function FG1 is not used since the propeller thrusts are not input.

The above two modes of operation allow for maximum program flexibility and simplicity. Test run data of both thrust and velocity is available from the installed XR-3 instrumentation. Thus, the simulation can easily duplicate any given set of operating conditions.

The force and moment equations for the propeller system of the XR-3 are derived from the propeller thrust diagram given in Figure 11. The figure displays the main thrust and side thrust vectors for both propellers positioned with right rudder angle a, positive pitch angle θ, and negative roll angle θ present. The thrust vectors act through the port and starboard propeller positions; xp, yp, and zp, from the craft center of gravity in the Body Reference coordinate system. These thrusts are then converted to forces in the local level reference coordinate system for the calculation of craft pitch, roll, and heave and forces in the Inertial Reference frame for calculation of craft trajectory. That is, the craft yaw angle Ψ, and x and y displacements.

The forces associated with the propeller arrangement of Figure 11 are depicted vectorially in Figure 12 in the Local Level Coordinate system. Employing the simplifications used in the derivation of the equations of motion namely that the pitch angle θ and roll angle θ are limited to small values, such that $\sin\theta \cong \theta$, $\cos\theta \cong 1$, and $\sin\emptyset \cong \emptyset$, $\cos\emptyset \cong 1$ the following force equations result:

T12 = THRUST 1 * COSa

T2X = THRUST 2 * COSa

ST1X = STHRUST 1 * SINa

ST2X = STHRUST 2 * SINa

T1Y = THRUST 1 * SINa

T2Y = THRUST 2 * SINa

PROPELLER THRUST DIAGRAM

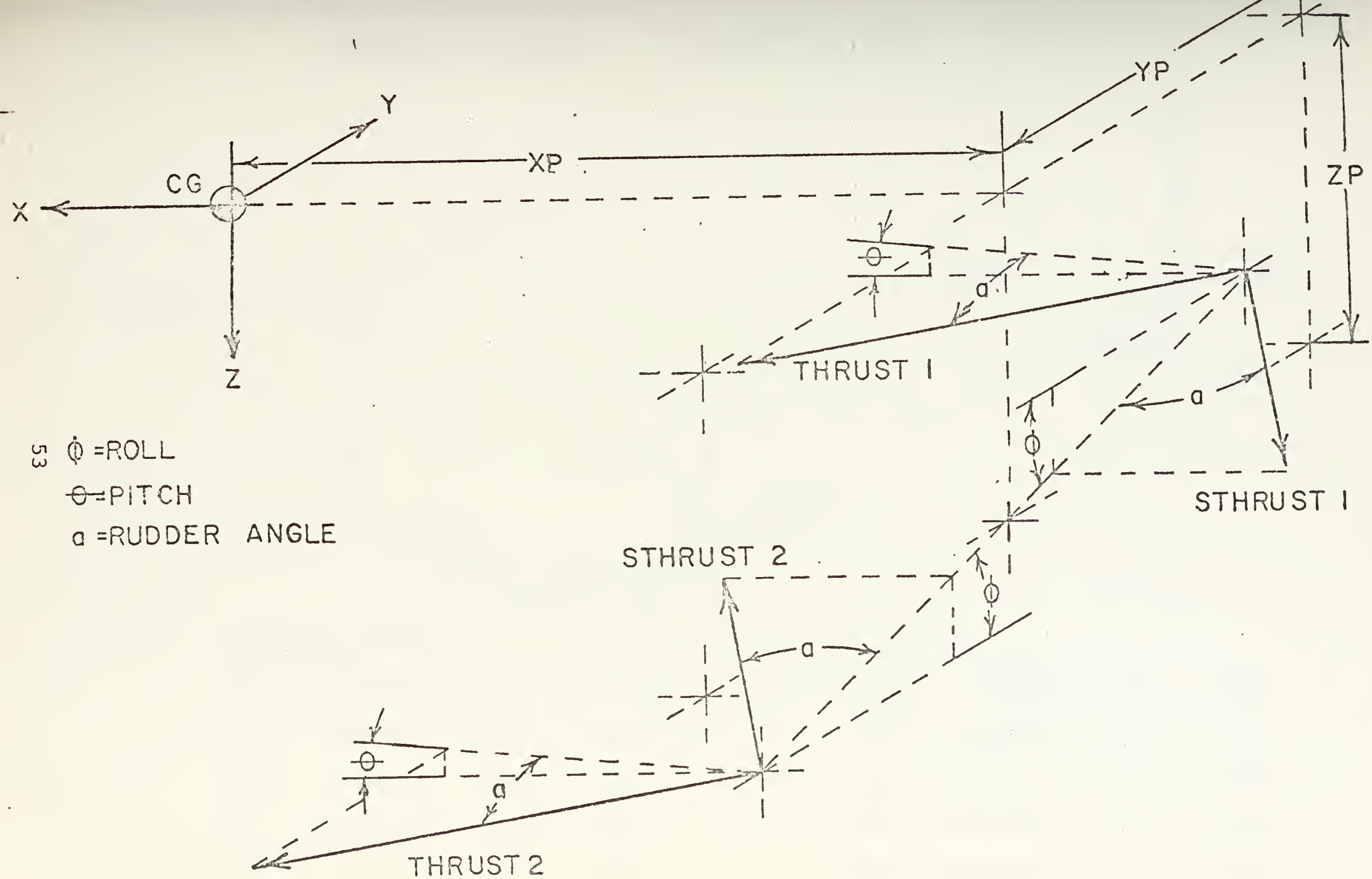
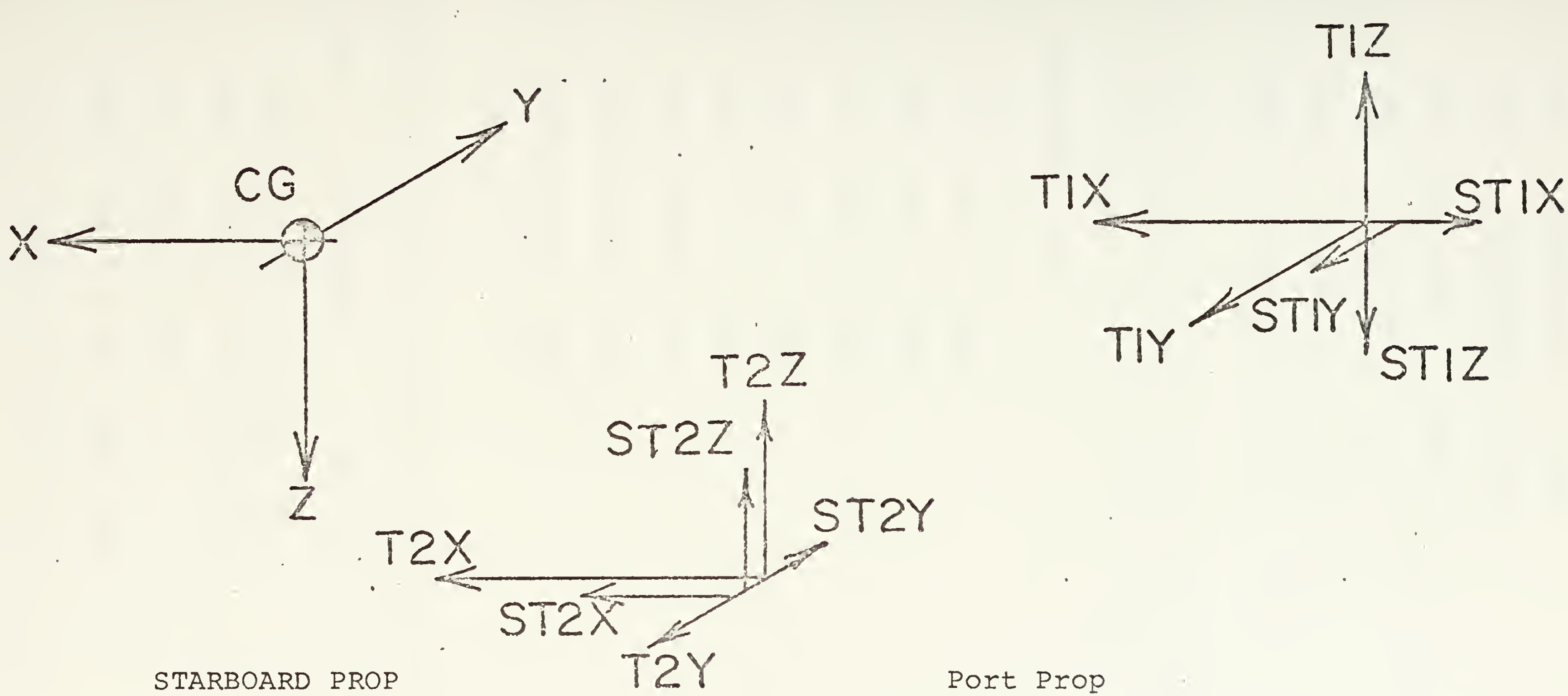


Figure 11

RESULTANT PROPELLER FORCES



STARBOARD PROP	Port Prop
T1X = THRUST 1 * COSa * COSθ	T2X = THRUST 2 * COSa * COSθ
T1Y = THRUST 1 * SINa * COSθ	T2Y = THRUST 2 * SINa * COSθ
T1Z = THRUST 1 * COSa * SINθ	T2Z = THRUST 2 * COSa * SINθ
ST1Y = STHRUST 1 * SINa * COSθ	ST2X = STHRUST 2 * SINa * COSØ
ST1X = STHRUST 1 * COSa * COSØ	ST2Y = STHRUST 2 * COSa * COSØ
ST1Z = STHRUST 1 * COSa * SINθ	ST2Z = STHRUST 2 * COSa * SINØ

Figure 12

$$ST1Y = STHRUST\ 1 * COSa$$

$$ST2Y = STHRUST\ 2 * COSa$$

$$T1Z = THRUST\ 1 * COSa * \theta$$

$$T2Z = THRUST\ 2 * COSa * \theta$$

$$ST1Z = STHRUST\ 1 * COSa * \emptyset$$

$$ST2Z = STHRUST\ 2 * COSa * \emptyset$$

By summation of forces in the three coordinate directions the following port and starboard propeller and total force equations result:

$$FXS = T1X + STIX$$

$$FXP = T2Z - ST2X$$

$$FX = FXS + FXP$$

$$FYS = T1Y - ST1Y$$

$$FYP = T2Y + ST2Y$$

$$FY = FYS + FYP$$

$$FZS = -T1Z - ST1Z$$

$$FZP = -T2Z + ST2Z$$

$$FZ = FZS + FZP$$

The moment equations associated with the preceeding force equations are given as:

$$FKS = FZS * YP - FYS * ZP$$

$$FKP = FZP * YP - FYP * ZP$$

$$FK = FKS + FKP$$

$$FMS = -FZS * XP + FXS * ZP$$

$$FMP = FZP * XP + FXP * ZP$$

FM = FMS + FMP

FNS = -FXS * YP + FYS * YP

FNP = FXP * YP + FYP * XP

FN = FNS + FNP

Throughout the preceeding representation it is assumed that the magnitudes of the main and side thrust vectors remain independent of the various rudder deflection angles a. It is also assumed that both port and starboard propellers rotate together through the same rudder defelction angles.

F. SUBROUTINE RHS

Subroutine RHS contains the expressions of the right hand side of the force and moment differential equations. These forces are calculated and summed in this subroutine.

Changes in this subroutine consist of modification of the Bubble Drag Coefficient of Friction, Common Block ties, and Center of Pressure Location. The rationale for these changes is presented in the section concerning the presentation of data.

G. SUBROUTINE RUDDER

The rudder subroutine used in the XR-3 simulation remains essentially unchanged with respect to its force and moment equations. However, some changes are introduced in the calculation of rudder deflection angle 'a' and in the input data to reflect the proper XR-3 rudder location and dimensions.

Rudder deflection angle can either be input as a constant angle in the input data set or it can be made to vary with time by using function FG1. Note, this rudder deflection angle is the same angle input to PROP subroutine to control the main thrust vector orientation.

As previously noted in the description of subroutine PROP, the motor/propeller housings constitute the XR-3 rudders. Physical measurements of these housings were used as rudder dimensions in the input data set. Each rudder/housing is located directly astern of its associated sidewall. They are vertically mounted and rotate in the horizontal plane.

The analysis of the XR-3 rudders assumes that they produce only lateral and drag forces. Lift or Z direction forces are considered negligible and hence they are set equal to zero.

The development of the force equations associated with the rudders of the XR-3 follows the analyses from references 9 and 7. The lateral force produced by both rudders is given by :

$$FY=2*RHO*U*U*A_r*(1+d/h)*RCLB*(a-(1+d/h)*V_h/U)$$

where A_r is the rudder area, RHO is the water mass density, U is the velocity in the X direction, d is the draft at the rudder, h is the draft plus the rudder span or length, RCLB is the lift coefficient for the rudder given as RCLB = 2AR/(AR+3) where AR is the aspect ratio, a is the rudder deflection angle, V_h is the first order approximation

rudder velocity in the lateral direction V_h is given by:

$$V_h=V+XR*R-ZR*P$$

with XR and ZR the coordinate locations of the rudder center with respect to the craft center of gravity.

The drag force produced by the rudders is given by

$$FX = -2*CD*A_r + RHO*U^2.$$

The drag coefficient is given by

$$CD = 2*CFR +PI/8 *(Tr/C)^2 * (1+G(h-d)/U^2) + RCLB*V_h'/U$$

where G is the gravity, Tr is the rudder thickness, C is the rudder chord, and CFR is the coefficient of friction given by the Schultz-Grünow formula

$$CFR = .427/(Log\ REY - .407)^{2.64}$$

where REY = U*Ar/(h-d)/ENU.

REY is commonly referred to as the Reynold's Number and ENU is the kinetic viscosity = $1.28 \times 10^{-5} ft^2/sec$.

The two preceeding force equations produce the following moments:

$$FK = -ZR*FY$$

$$FM = ZR*FX$$

$$FH = XR*FY$$

H. SUBROUTINE SIDEWALL

Changes made to the sidewall subroutine consist of the removal of force computations associated with ventral fins which are not present in the XR-3 testcraft. The remainder of the subroutine is unchanged from the Bell 100 ton craft version described in reference 9 .

The hydrodynamic and hydrostatic forces and moments acting on the sidewalls are found by application of slender body theory. This theory, based on motion of a foil in a viscous medium, developes methods for finding the lift and drag forces associated with moving underwater bodies. These methods are primarily linear in nature as shown in references 1 and 9 with the effect of instantaneous changes in immersed sectional area, draft, etc. due to orientation changes arising from heave, pitch, and roll motions reflecting the most significant nonlinear variations. The sidewall forces also contain certain nonlinear terms due to cross-flow drag, which are important for the case of very low aspect ratio lifting surfaces as are the XR-3 sidewalls. The sidewall forces will then be composed of two separate contributions; first the terms due to sidewall buoyancy and slender body hydrodynamic reactions and second the effect of cross-flow drag, i.e.

$$R_{sidewalls} = FH_{sw} + FD_{sw}$$

where FH forces result from slender body theory, and FD forces are the result of the cross-flow drag terms.

Although no changes were made to the sidewall subroutine force and moment equations they were considered of adequate importance to be here discussed.

Before computing the forces on the sidewalls, the subroutine first calculates the draft of or the gap beneath the sidewalls. The draft/gap is found for each X-direction section after it has been corrected for craft roll and pitch angles and waves. If gaps are present, then the total sidewall leakage area ALSW is computed by summing the products of gap heights and sidewall section lengths for both sidewalls.

1. Cross-Flow Drag Terms

The cross-flow drag force components are assumed to only be significant for the lateral force, yaw moment, and roll moment. While such forces are also present in the vertical force and pitch moment, they are not as large relative to the predominant forces due to bubble pressure and are neglected. The lateral force due to cross-flow drag on a single sidewall is given by:

FYD=-RHO/2*CDC*VREL*ABS(VREL)*DELX*DSWAV

where VREL = V + XAVG*R -((ZS-DSWAV)/2) *P and DELX is the length of each sidewall section, DSWAV is the draft of the ith sidewall section corrected for waves,(ZS-DSWAV)/2 is the average Z distance of the ith sidewall section from XREF where XREF is input as 9 feet forward of the transom.

These expressions are appropriate to the particular values associated with sidewall sections in either the port or starboard side. The yaw moment due to cross-flow drag is

FND = FYD *XAVG

where XAVG is the average X distance of the ith sidewall element form XREF. The roll moment is given by

FKD = FYD * (ZS - DSWAV /2)

The total force and moment values due to cross-flow drag are then

FYD = FYD (1) + FYD (2)

FND = FND (1) + FND (2)

FKD = FKD (1) + FKD (2)

where the subscripts (2) and (1) indicate the port and starboard sidewalls respectively.

The cross-flow drag coefficient is the value corresponding to that for flow normal to a long flat plate, with a value of CDC = 1.28.

2. Slender Body Theory Terms

Following the procedures indicated in reference 9, together with evaluation of all integral terms involving derivatives of sectional properties by means of integration by parts the following results are found for a single sidewall (port or starboard, using appropriate values for each): The X-direction sidewall drag force is given by

FXH=-RHO/2*CDT * WAREA * U * U

where WAREA is the wetted area of a sidewall section corrected for draft, roll, and pitch. CDT is the computed drag coefficient.

The Z-direction sidewall force corrected for added mass effect is given by

FZH = -G *BCO -U*U*A33S*THETA - U *A33S *W + Q *
U * (A33S * XSS - BC2) - U*A33S * P *YLSW

where BCO is the mass of the water displaced by the ith sidewall element which causes a negative buoyant force, A33S is the vertical added mass of the ith sidewall element given by A33S = RHO * π * BS **2/8 , where BS is its beam. BC2 is the total sidewall vertical added mass and YLSW is the lateral distance of the ith sidewall element form the centerline.

The hydrodynamic lateral force is given by

FYH = -A22S * U * (V + XSS * R - ZS * P)

where A22S is the lateral added mass at the stern given by

A22S = RHO* .4 * PI * DSS**2/2

where DSS is the sidewall draft. The moment about the Y-axis is given by

FMH = -U *XSS*XSS* ASS3 * Q + G*BCOO + U *
(A33 * XSS+BC2) * (W+U *THETA+YLSW*P)

where BCOO is associated with the sidewall volume between XREF and XS. This computation is available by entering a table of values computed offline in program SIDETAB and stored in common block WAVTAB by the INCON subroutine.

The moment about the Z axis is given by

FNH = FYH *XSS -U * ((V-ZS *P) * BC5 + BC 6*R)

where BC5 is the total lateral added mass and BC 6 is the moment associated with the total lateral added mass.

The total slender body theory and crossflow forces, and moments for both sidewalls are then given by

FX = FXH (1) + FXH (2)

FY = FYH (1) + FYH(2) - FYD

FZ = FZH (1) + FZH (2)

FK = (FZH (2) - FZH (1))* YSW - ZS * FY + FKD

FM = (FMH (1) + FMH (2))+ ZS * FX

FN = (FXH (1) - FXH (2))*YSW + FNH (1) + FNH (2) +FND

In the calculation of the individual sidewall force terms it is understood that the computation is appropriate to the instantaneous values of the separate elements as the vehicle moves.

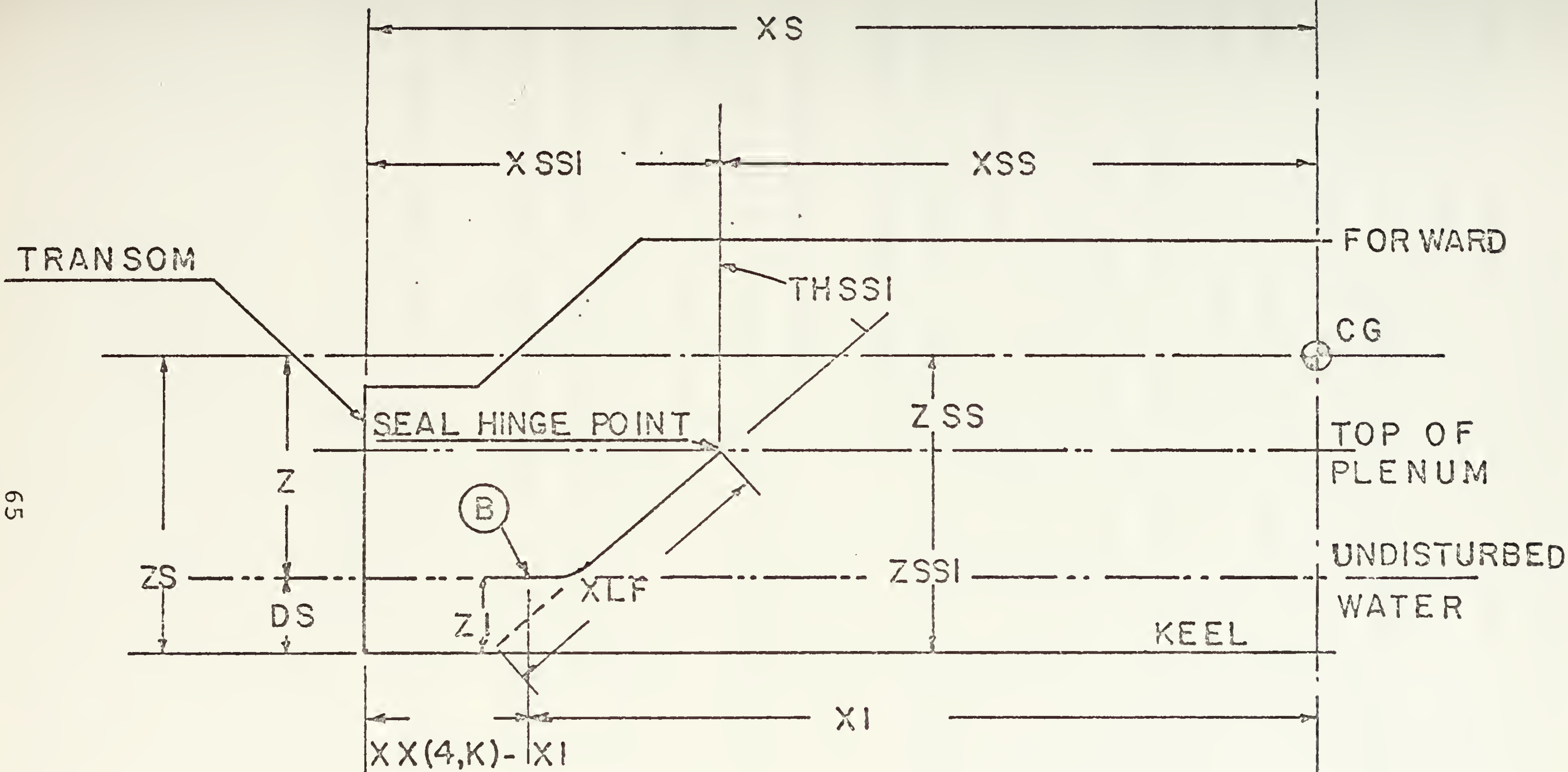
I. SUBROUTINE STERN SEAL

Since the bow and stern seals of the XR-3 are similar except for location the subroutines also are similar except for variable names.

Reference to Figure 13 and the list below will acquaint the reader with the important variable names.

Dimension	Origin
XS	INCON ROUTINE BLOCK 225. XS is calculated by locating the CG and there calculating the distance to the transom.
XSSI	INCON ROUTINE BLOCK 500. This is input as the distance from the transom to the hinge point of the seal.
ZS	INCON ROUTINE BLOCK 200. ZS is calculated in the same manner as XS except that it measures the vertical distance from CG to the keel.
ZSSI	INCON ROUTINE BLOCK 500. This is the vertical distance from the hinge to the keel.
XSS	This is calculated in INCON BLOCK 1302, using the information XSSI and XS and represents the horizontal distance from the center of gravity to the seal hinge.
ZSS	This is calculated in INCON BLOCK 1302 using the information provided by ZSSI and ZS and represents the distance from the center of gravity to the hinge.
THSSI	This is the angle of the seal face made with the craft vertical and is input in block 500 of INCON.

Lift and drag forces in the stern seal result from the pressure differential between the seal and the plenum and the amount of the seal in contact with the water respectively. Since the plenum exhausts mainly under the stern seal we assume the bubble to extend to the tip of the stern seal.



CALM WATER
ROLL= 0.0
PITCH = 0.0

STERN SEAL
CONFIGURATION

Figure 13

Thus the stern seal becomes an air lubricated surface and the plenum pressure is extended all the way under the seal to the atmosphere.

We can then assume that the forces acting upward concentrate themselves at the point (B) in Figure 13 which represents the mid-point of the wetted surface. It is also logical to exert the drag forces at this same point, since they act along the wetted surface, the surface of friction.

We find that the forces in the Z direction are much less than in the bow seal because the differential pressure is so much less than in the bow seal. The bow seal is acting against atmospheric pressure while the stern seal is acting against the plenum pressure.

J. COMMON BLOCK TIE MAP

The Common Block Tie Map shows which common blocks appear in each subroutine.

The map is read by finding the common block in the left hand column and then reading to the right. An X appears in each column under the subroutine in which that common block appears.

Some common ties have only one entry. This results from the removal of the SAM subroutine.

COMMON BLOCK TIE MAP

SUBROUTINE NAME / COMMON BLOCK NAME	MAIN	AEROD	BOWSL	COLFIL	FAN	INCON	INTGRL	PROP	RHS	RUDDR	SIDEWL	STNSL	WAVES
AIR	X		X		X	X			X		X	X	
AXIS				X		X							
BMCO	X					X	X		X		X		X
COLUMN				X		X			X				
CONST	X		X			X		X	X	X	X	X	X
CNTRL						X			X				
CURVE				X		X							
ENGINE	X					X		X	X				
EQNCO	X					X	X						
FAERO		X							X				
FAIR		X				X							
FANMAP					X	X			X				
FORBS			X						X				
FORSS									X			X	
FPROP	X							X	X				
FROUDE	X					X			X				
FRUD									X	X			
GBOW						X			X				
GEOM			X			X			X		X	X	X
GEOMBS			X						X				X
GEOMSS									X			X	X
GEOMSW						X					X		

COMMON BLOCK TIE MAP (CONT.)

SUBROUTINE NAME / COMMON BLOCK NAME	MAIN	AEROD	BOWSL	COLFIL	FAN	INCON	INTGRL	PROP	RHS	RUDDR	SIDWL	STNSL	WAVES
GRAF				X		X							
HEADG				X		X							
KSWITCH							X		X		X	X	
LEAKER			X			X						X	
MASSES			X			X	X		X	X	X	X	X
MATRIX						X			X				
MSIDW									X		X		
MWAVE									X				X
OPTION						X			X				
PLENUM						X			X		X		X
PRIME	X					X	X		X		X		
PRTINT	X	X	X		X	X	X	X	X	X	X	X	X
PWAVE						X			X				
RISER						X							X
ROLL	X					X							
RUDDR	X					X		X	X	X			
SIDE						X			X		X		X
SOFTBS		X			X	X			X				
SOFTSS					X	X			X			X	
STABLE						X	X						
STSLR						X						X	
SUM				X		X							

COMMON BLOCK TIE MAP (CONT.)

SUBROUTINE NAME / COMMON BLOCK NAME	MAIN	AEROD	BOWSL	COLFIL	FAN	INCON	INTGRL	PROP	RHS	RUDDR	SIDWL	STNSL	WAVES
VALOLD	X					X	X		X			X	
VARBLE	X	X	X		X	X	X	X	X	X	X	X	X
WAVE	X		X			X			X		X	X	X
WAVEF						X							
WAVTAB						X					X		X

IV. PROCEDURES

A. OBTAINING STEADY STATE

Following program modification to reflect the geometry of the XR-3, program runs were made to obtain steady state conditions. This was accomplished by comparing steady state program outputs of thrust and pitch angle with measured data obtained from the XR-3 testcraft. The testcraft measured data consisted of steady state thrust and pitch angle measurements made at several velocities between 10 and 25 knots in calm water. These measured data formed the basis upon which program modifications were to be made.

It was first necessary to change the thrust versus velocity curve produced by the program so that it coincided with the measured data. This was accomplished by adjusting the bubble frictional drag coefficient to bring the lower portion of the curves into agreement. A similar agreement was obtained at the high end of the curve by adjusting the skin frictional drag. This drag is a direct result of craft draft, and is therefore not easily obtained. Adjusting draft requires that both plenum pressure and fan flow be maintained in such a manner that the appropriate lift is attained without exceeding the horse power limitation of the fan engines. Successive runs using the constant speed, trim option of the program were made at various drafts until the appropriate values of thrust for a velocity was obtained.

Having found that draft which produces the required drag, hence, the proper thrust, bubble pressure and stern seal leakage were adjusted to bring the forces in the Z direction into balance. To accomplish this the plenum pressure that produced the required lift was found and then the stern seal leakage was adjusted to provide the proper fan flow which maintained fan engine horsepower within its limits. A small portion of the total seal leakage was assumed to exist at the joints between the bow seal and sidewalls, the remainder being under the stern seal.

No attempt has been made to provide agreement between the craft transient behavior and that of the program. However, the data herein presented appears to show that there is a fair amount of agreement in this area. The transient behavior of the craft and the simulation program provide a very fertile area for further investigation.

B. DIFFERENCES ENCOUNTERED IN THE MODEL

1. Seal Configuration

For reasons previously stated, the mathematical model of the 100B stern seal was selected to represent both seals on the XR-3. The forces calculated by the simulation program employing this model appear to be reasonable. That is, they are of the same order of magnitude as those scaled from the 100B. Leakage coefficients were not changed since the type of orifices employed on the XR-3 were considered to be similar to the 100B.

2. Plenum Dimensions

For a first try at implementing craft plenum geometry actual craft measurements were taken and used as input data to the simulation program. However, it was found that these dimensions did not produce appropriate XR-3 force and moment relationships. Through investigation of XR-3 model data and subsequent program utilization the arbitrarily chosen nominal values of 10 and 20 feet, plenum width and length respectively, provided the desired results. Lift due to plenum pressure was highly sensitive to these plenum dimensions. Therefore, when more accurate plenum pressure data becomes available these dimensions may require some refinement.

C. SENSITIVITY TO CHANGES TO INPUT DATA

It was found that the XR-3 is extremely sensitive to the initial conditions included in the input data set. Small disagreement between the required initial conditions and those input, produce violent transients that can cause the program to stop execution or to give erroneous results.

Two of the most critical input parameters are craft draft and plenum pressure. This is true because the plenum pressure and draft are closely interrelated and cannot be separated for analysis. The plenum, having a large surface area, exerts the greatest single force on craft dynamics. Hence, a very small change in plenum pressure operating on this large surface area, 200 square feet, produces a significant

change in the Z direction force. Thus, imbalance of either draft or pressure, or draft and pressure, cause transients too great for the simulation to accept. These results also suggest that rapid maneuvers or inputs approaching step-functions will also produce transients too great to be adequately computed.

It is recommended that an investigation be conducted to determine methods of improving the integration procedure to allow very rapid maneuvers.

D. POSSIBLE ERRORS IN THE PROGRAM

Many coefficients herein described were assumed to be correct. However, this may not be the case. Those coefficients that are calculated by their definitions such as Reynolds number and Froude number are most probable correct. However, leakage orifice coefficients, skin friction coefficients and the bubble drag coefficients have not been verified, though they seem to give adequate results.

Other coefficients unknown to be exact are the moments of inertia. The simulation program provides a method for accurately calculating the moments of inertia, I_X, I_Y, I_Z and I_{XZ}. This option was not employed because accurate weight distribution data was not available. The moments of inertia I_X, I_Y and I_Z were obtained from references describing the craft prior to many major modifications. Not the least of which was the installation of the auxiliary power supply and the replacement of bow and stern seals.

These modifications added a considerable percentage to the total craft weight. These weight additions were concentrated in several locations. Hence, the scaled values of I_X, I_Y and I_Z used in the simulation cannot be relied upon as being accurate.

No available data could be found concerning the product moment of inertia I_{XZ}. This moment of inertia is required when attempting to execute maneuvers involving turns or off centerline craft motions. Therefore, an estimated value using size scaling was employed and rendered reasonable craft motions under the above conditions.

To determine the correct moments of inertia, it is recommended that a thorough craft mass distribution analysis be conducted and the resulting parameters be input to the program utilizing the option mentioned above.

A third area open to further improvement is that of refining the dimensions input to the sidewall map of the side geometry subroutine. The present representation for the XR-3 sidewalls loses much computational accuracy due to the large vertical stepsize presently used.

A remapping of the sidewall geometry is required to more accurately describe the curvature in the lower regions of the sidewalls. This would result in the subroutine providing more refined values of sidewall volume and surface area for the various XR-3 drafts and attitudes which are important for the calculation of sidewall forces and moments.

Notwithstanding the above areas in which error exists it is felt that the craft data and figures tend to indicate that the simulation program is a valid representation of XR-3 motion.

V. PROGRAM VERIFICATION

A. INSTRUMENTATION AND RECORDED DATA

Instrumentation as presently installed in the XR-3 includes the following:

1. Two strain gauges mounted directly on the engine mounts measure the thrust of the propulsion system.
2. A rate Gyro mounted near C.G. is used to measure pitch and roll angles.
3. A turbine type flowmeter which extends forward in undisturbed water measures velocity.

Additional instrumentation presently operational on the XR-3 measures yaw, pressure in the plenum and seals, and rudder angles. The output from these sensing devices are recorded on a 14 track Pemco Model 120B Magnetic tape recorder. Hard copies of the measurement data are obtained using a Hewlitt Packard two channel chart recorder. No filtering other than that natural filtering caused by the frequency response of the recorders was used with the result that the data was quite noisy. The noise was considered to be white and gaussian, therefore the mean value of the resultant curve was taken as the best estimate of the variable under cosideration.

Shown in Table I are the data collected from test runs made by the XR-3 at Lake San Antonio, California, over a one-day period in calm water and no wind conditions. Each

entry represents a steady state condition.

Table I. Test Craft Measured Data

Velocity in kts.	Thrust in pounds	Pitch angle in degrees
8.5	405	Not available
9.0	425	Not available
10.5	520	1.6
12.0	475	1.55
13.0	453	Not available
14.0	490	1.4
14.5	400	Not available
15.0	465	.8
16.5	407	Not available
17.0	395	Not available
19.0	415	Not available
19.5	425	Not available
20.0	440	.2
21.0	455	Not available
22.0	460	Not available
22.5	455	Not available
23.0	480	Not available
24.0	496	Not available
24.5	510	0.1
25.0	509	Not available

B. L&M PROGRAM DEVELOPED DATA

1. Steady State Trim Conditions

Steady state trim conditions for the XR-3 using the L&M program were difficult to obtain. It was observed that the program initial conditions must be very close to the steady state values or the imbalance in forces generated within the program is so great that one of two cases occurs.

Case 1 using Variable Time Step (R-K-M)

The force imbalance causes such a radical transient that, in order not to lose curve information, the integration step size is reduced until the minimum allowed step size is reached and the program execution stops.

Case 2 using Fixed Time Step (R-K)

The danger in this method is that the step size may be too great (note: in some cases, .01 seconds is too large) and curve information is lost. When information is lost the program calculations begin generating erratic number values thus causing an underflow or overflow condition to exist within the program which stops program execution. Thus, care must be exercised in selecting a stepsize to be used. The results shown in Table II were obtained using the fixed step size option with a step size of .001. The constant speed and variable thrust options of Block 1 of the INCON Subroutine were selected. Since the force equations of the program are dependent upon speed, using these options removes the surge equation from the computations and adjusts thrust to balance the forces in the X direction.

Table II. L&M Program Initial Conditions

Speed (in knots)	Thrust (in pounds)	Pitch Angle (in degrees)	Draft (in inches)
10.0	504.6	1.72	6.6
12.5	419.3	1.31	6.5
15.0	392.4	.94	6.35
17.5	397.8	.6	6.15
20.0	424.7	.29	5.98
22.5	464.7	.13	5.78
25.0	512.8	.09	5.56
27.5	567.3	.06	5.3
30.0	625.5	.05	3.02

Plenum pressure 24.86 psf

To balance the forces in the Z direction short time runs of .01 seconds or less were used. For each run adjustments were made to the initial draft and/or plenum pressure to bring these forces into balance. Care was taken to avoid fan flows and pressures above that level requiring greater than 15 horsepower, which is the maximum horsepower available from the fan engines. Continuing in this manner the initial trim conditions of draft, pitch angle, and thrust required were obtained for each of the speeds shown in Table II. Once these initial conditions were known, the step size was increased to .01 and it was found that no curve information was being lost indicating that the transient was of a less violent nature. Long time runs using the variable time step size verified that these values were the correct initial trim conditions. A straight line segment was used to join the points so that linear interpolations may be used between the tabular values.

To obtain good agreement between measured and simulated data required the manipulation of two quantities that produce total ship drag; the bubble drag, FXPWAV, and the skin friction drag FX. Adjustment of the forces in the X direction was accomplished by adjusting draft to provide the proper drag force at the upper end of the velocity curve where the frictional drag component exerts the greatest influence over total ship drag. The next step was to adjust the coefficient of the bubble drag to provide the minimum point in the total drag curve at the velocity indicated by Table II, about 17.0

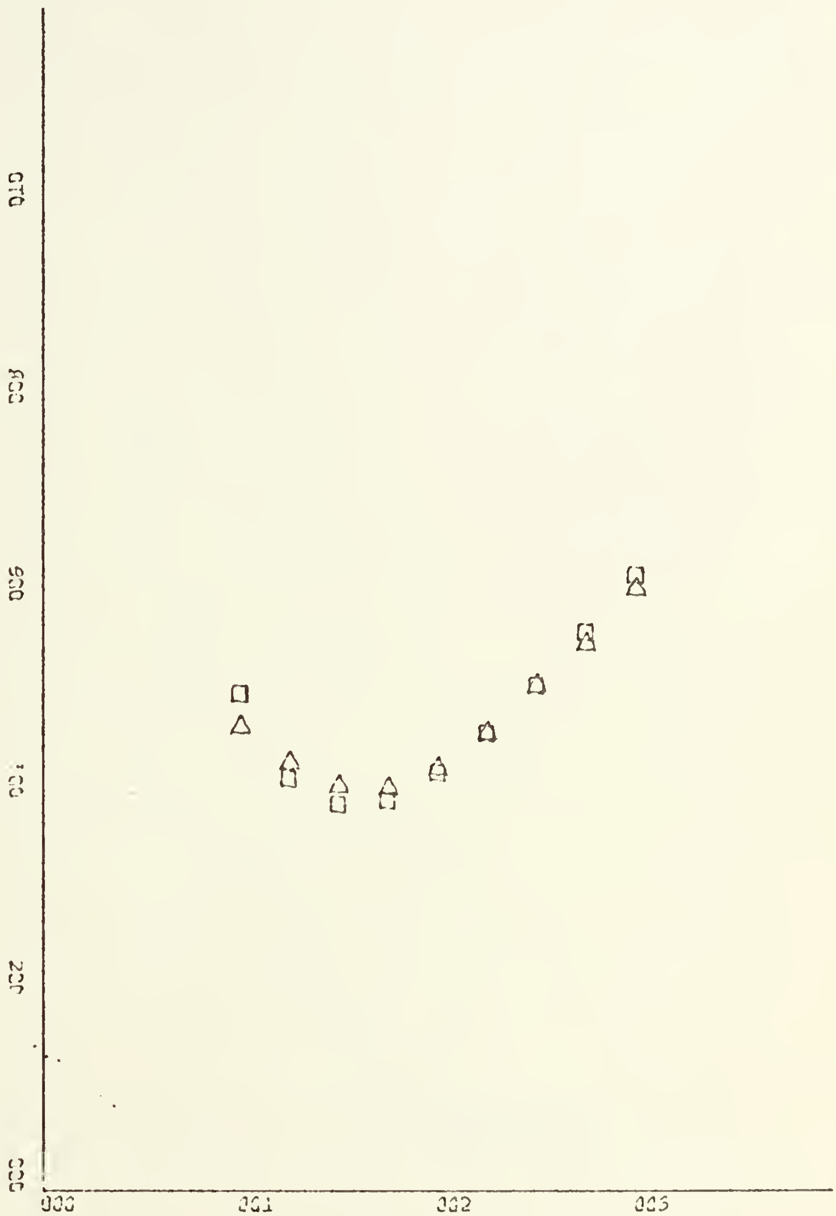
knots, and to also provide the required drag at the low end of the drag curve where the bubble drag exerts the greatest influence.

To obtain agreement between measured and simulated pitch angle required some programming changes. Reference 11 indicates that a pressure gradient exists in the plenum chamber. This gradient is such that as the craft increases in speed the center of pressure moves aft. This causes the craft to have a pitch up attitude at slow speeds and a gradually smaller positive pitch as speed increases. Using the experimentally measured data shown in Table I, a set of points representing the craft center of pressure position as a function of speed was calculated which would produce the appropriate craft pitch angle for a given speed. A linear function used to approximate these points was then included in the simulation program.

Figures 14, 15 and 16 show plotted points of the two tables of data. Triangles represent experimentally determined data and squares the program output. Clearly the program simulates quite well the thrust and pitch angle curves. Accurate data on draft was not available from XR-3 tests due to a defective height sensing device. However, it is felt that the draft data when available will closely fit the curve shown.

2. <u>Presentation of Unverified Program Data</u>

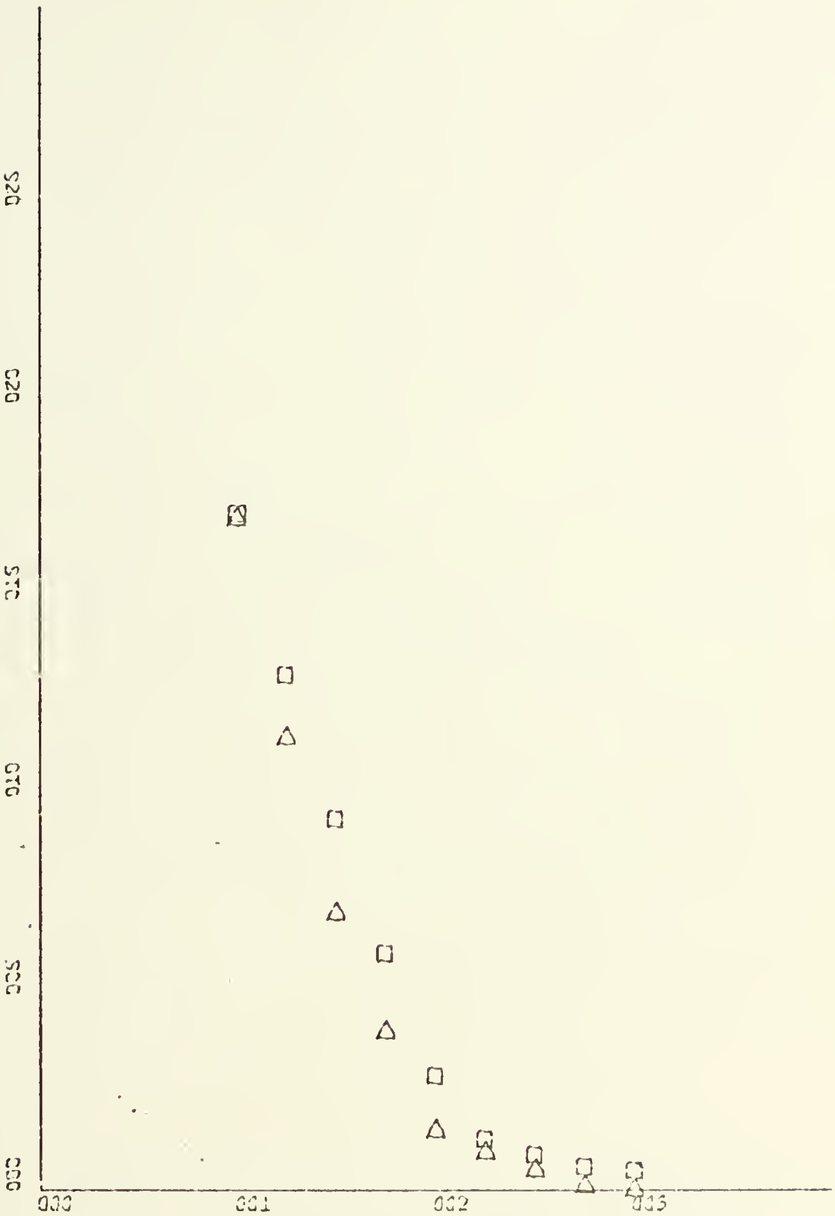
Figures 17, 18 and 19 demostrates the use of the variable thrust option. Thrust is input to Subroutine PROP



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

XR-3 THRUST VS. VELOCITY

Figure 14



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.

XR-3 PITCH ANGLE VS. VELOCITY

Figure 15

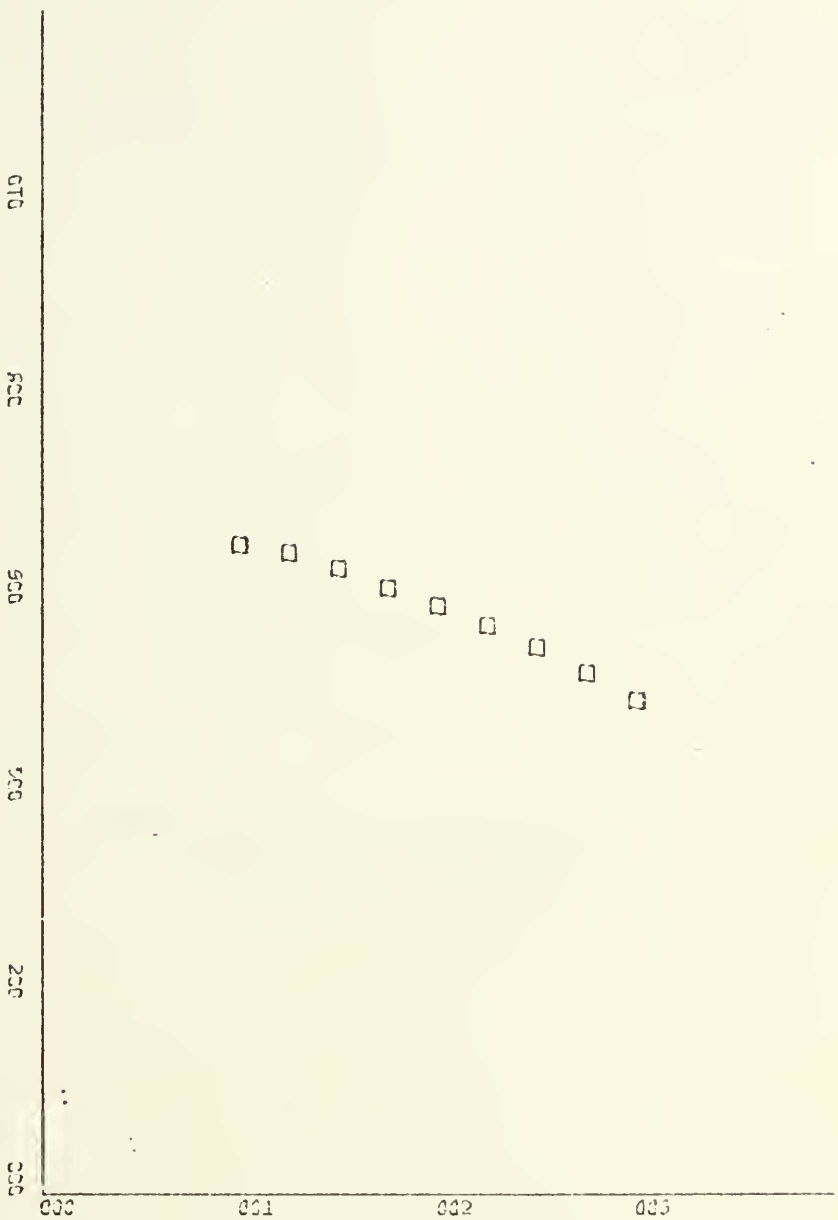


Figure 16

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E+00 UNITS INCH.

XR-3 DRAFT VS. VELOCITY

Figure 17

THRUST CHANGE: Speed versus Time

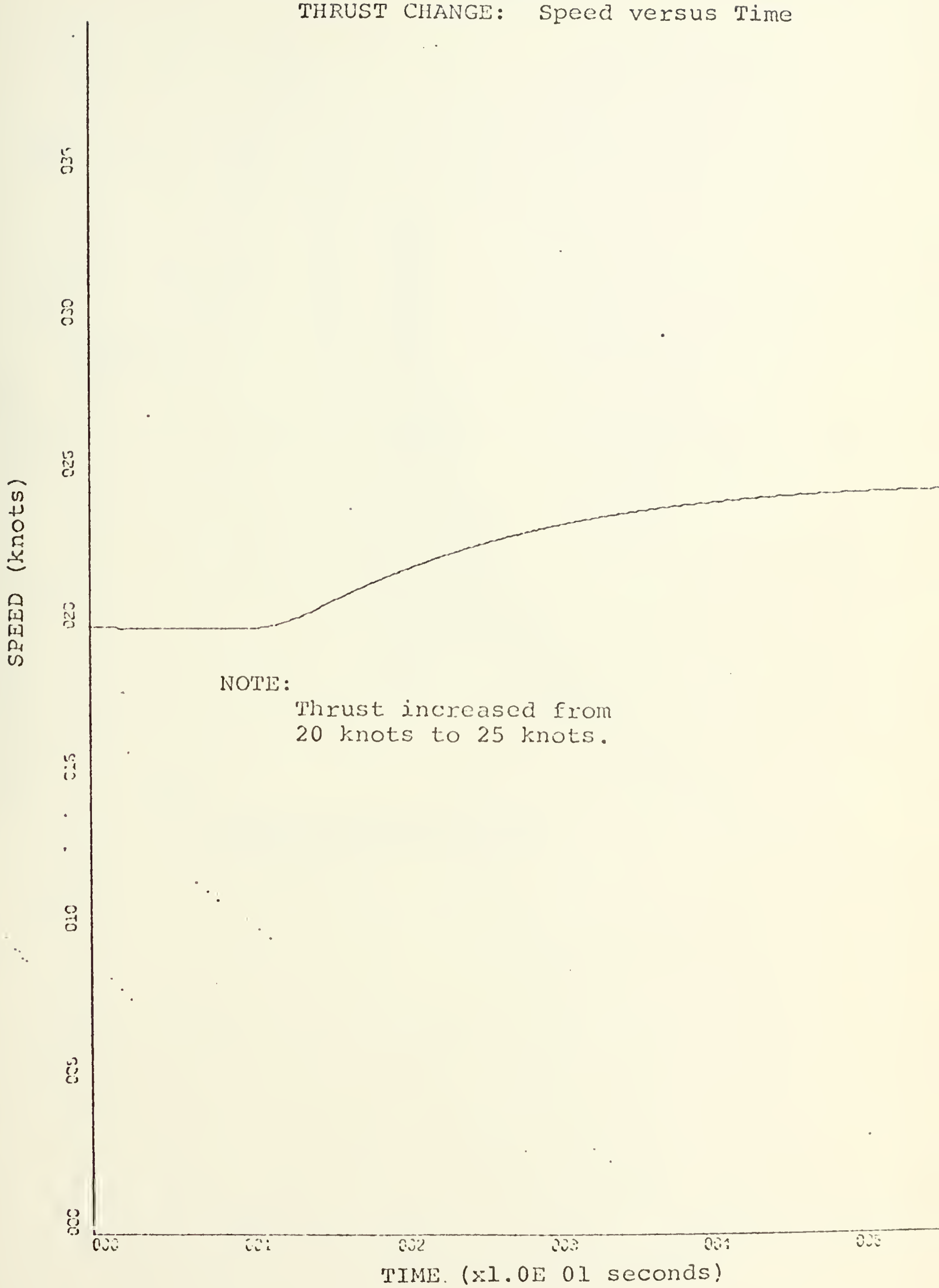


Figure 18

THRUST CHANGE: Pitch Angle Versus Time

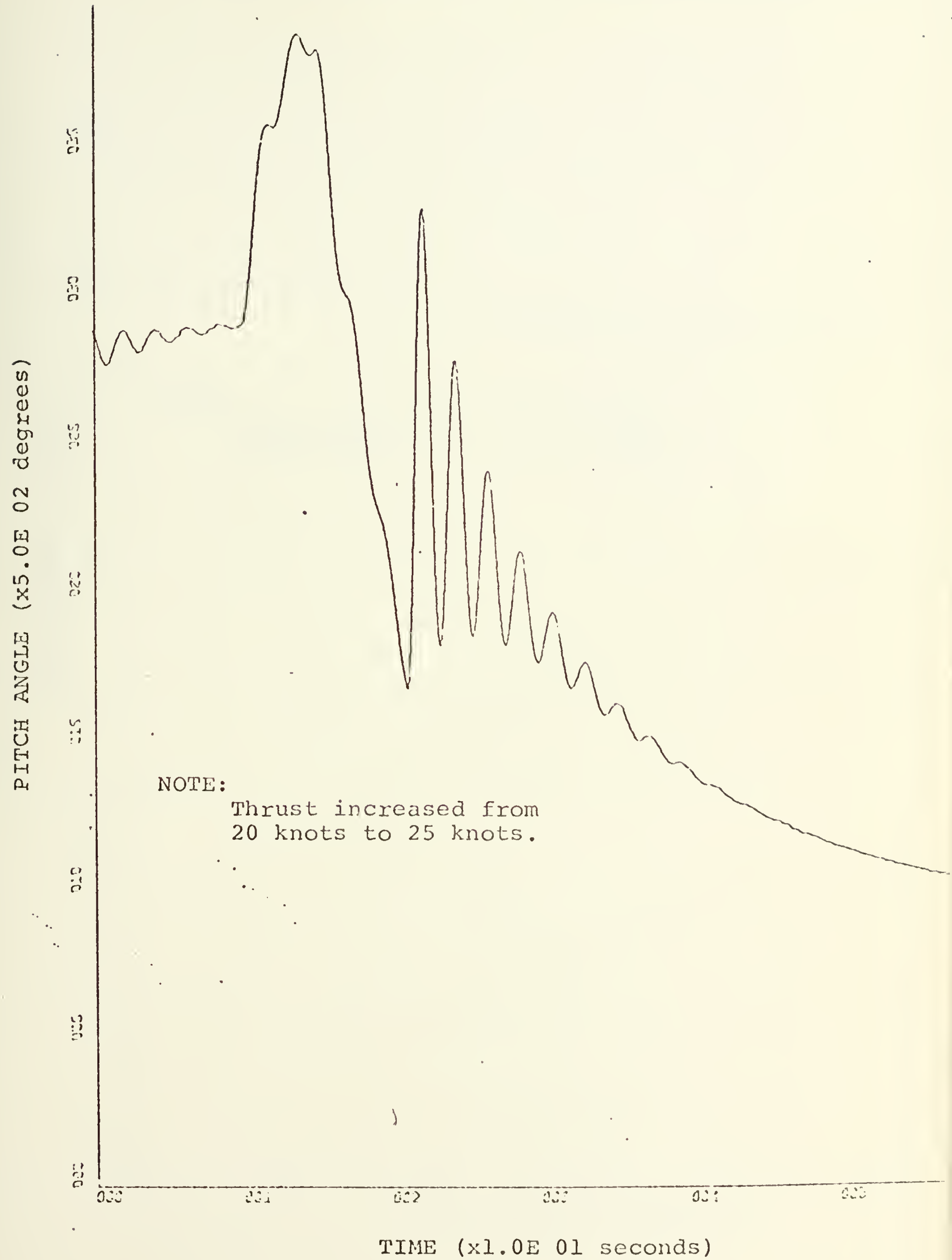
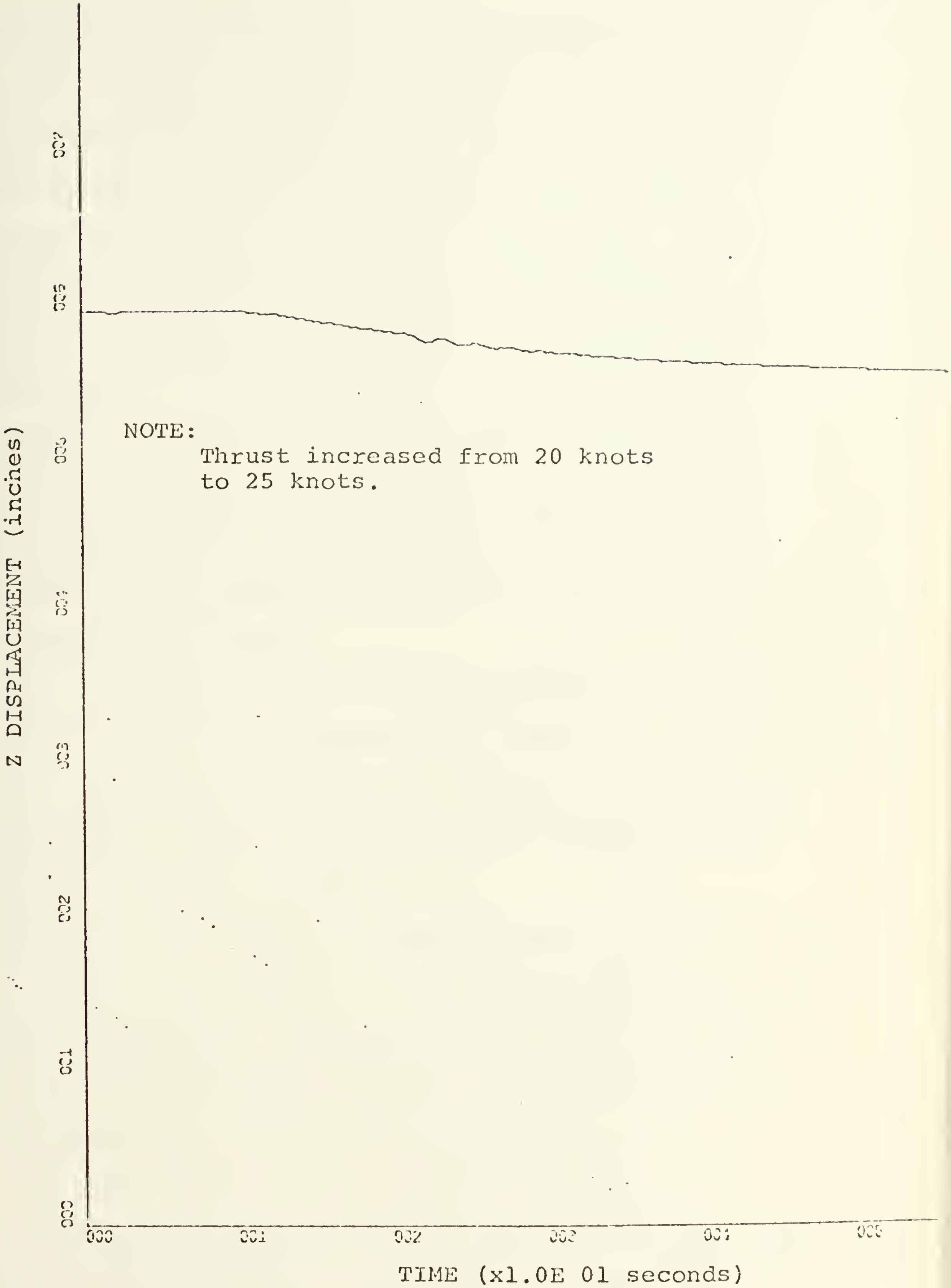


Figure 19
THRUST CHANGE: Z Displacement versus Time



utilizing the Block 16 variable thrust option of Subroutine INCON. This thrust is applied equally to both screws and is mapped as follows. Thrust for 20 knots is initially applied and maintained for 10 seconds. Between time 10 seconds and time 15 seconds the craft experiences a ramp function of thrust building up to the tabular value for 25 knots. This thrust is maintained for the remainder of the run.

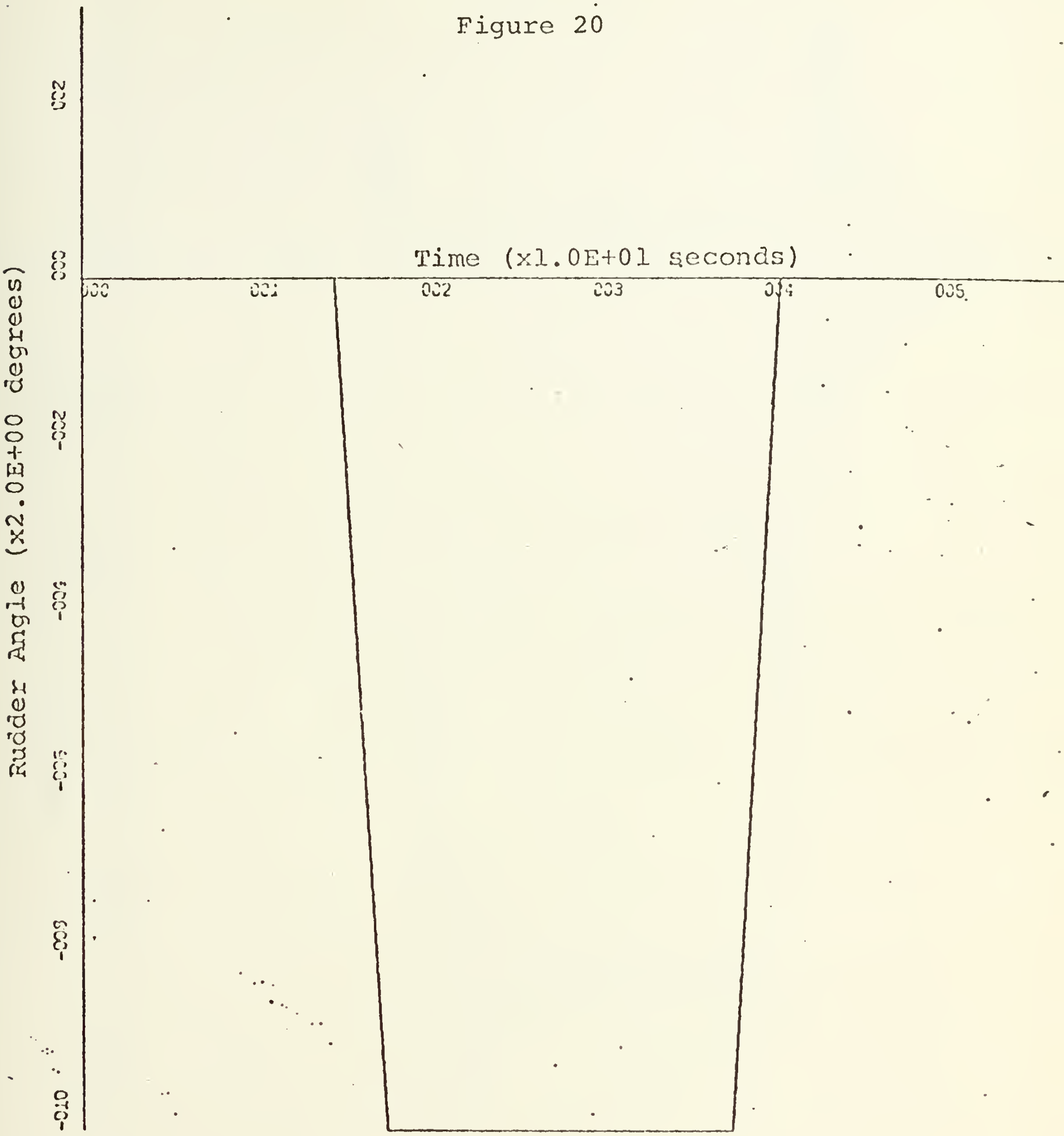
Figure 18 shows that the pitch angle follows the expected curve, in that initially pitch up is experienced as additional thrust is applied. This is followed by gradually dampening oscillations toward the value of pitch angle expected at 25 knots.

Figures 17 and 19 show that speed through the water increases and that draft decreases, as expected. Additionally, examination of Block 16 of Subroutine INCON makes it clear that the engines may be unevenly thrusted rather than equally thrusted as shown.

Figures 20, 21, 22 and 23 show the behavior of the program for a turning maneuver. The rudder input vs. time is shown in Figure 20. Corresponding roll angle vs. time, pitch angle vs. time, and the ship horizontal plane motion are in Figures 21, 22 and 23 respectively.

It is interesting to note that the roll and pitch damping coefficients appear to be different during the time the rudder is off centerline than when the rudder is returned to centerline. However, these differences are to

Figure 20



20 Knot Turn: Rudder Angle vs. Time

Figure 21

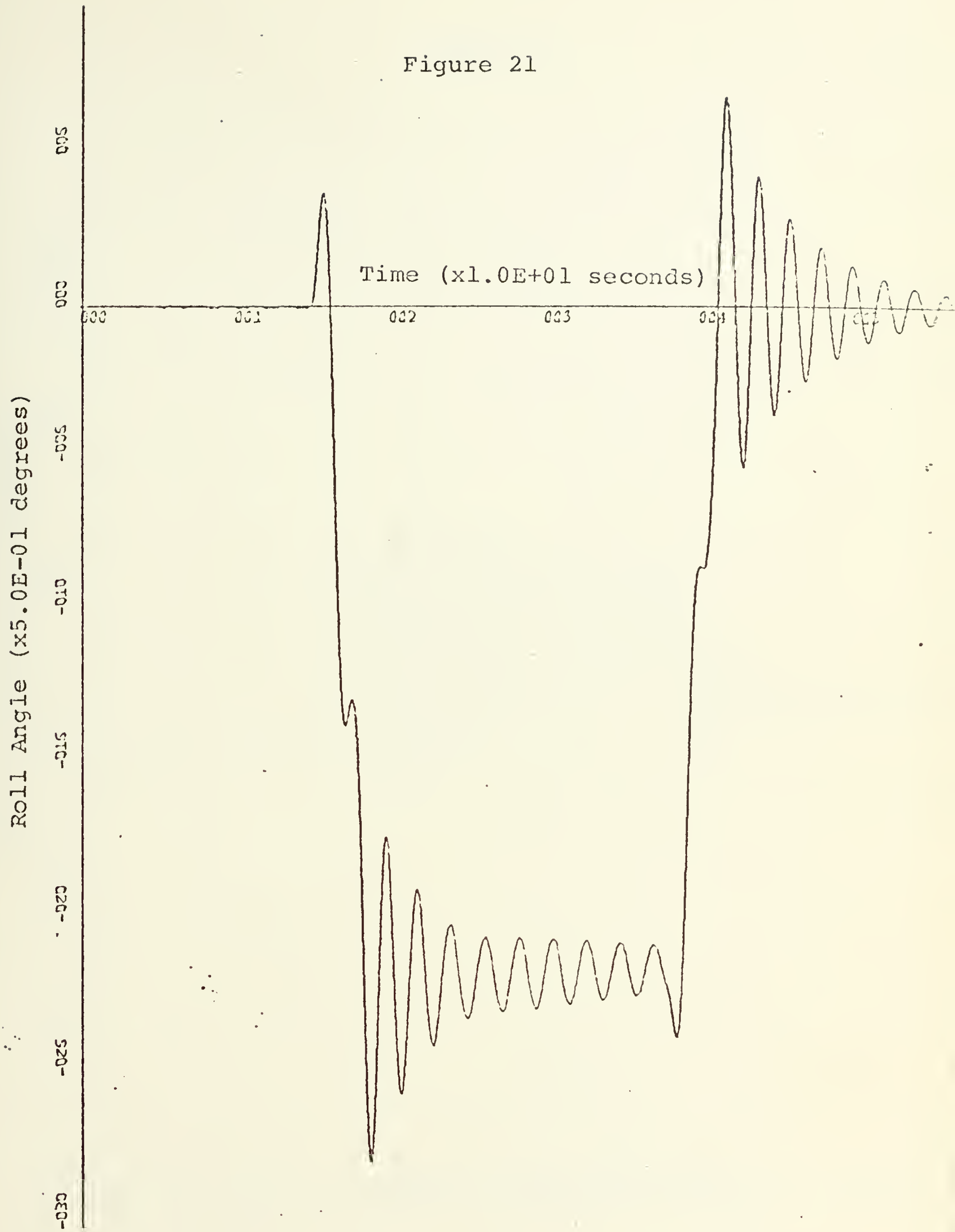
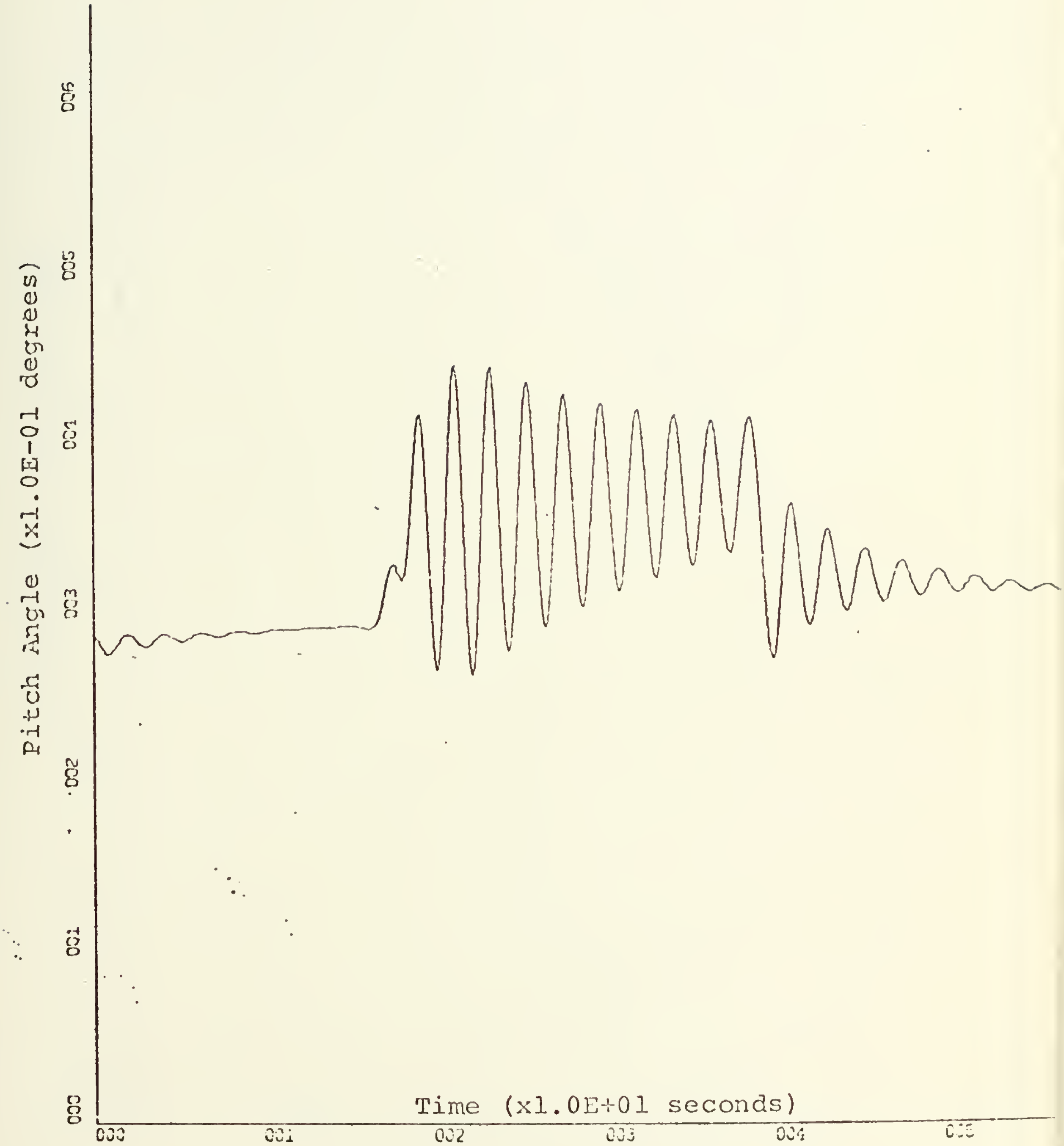


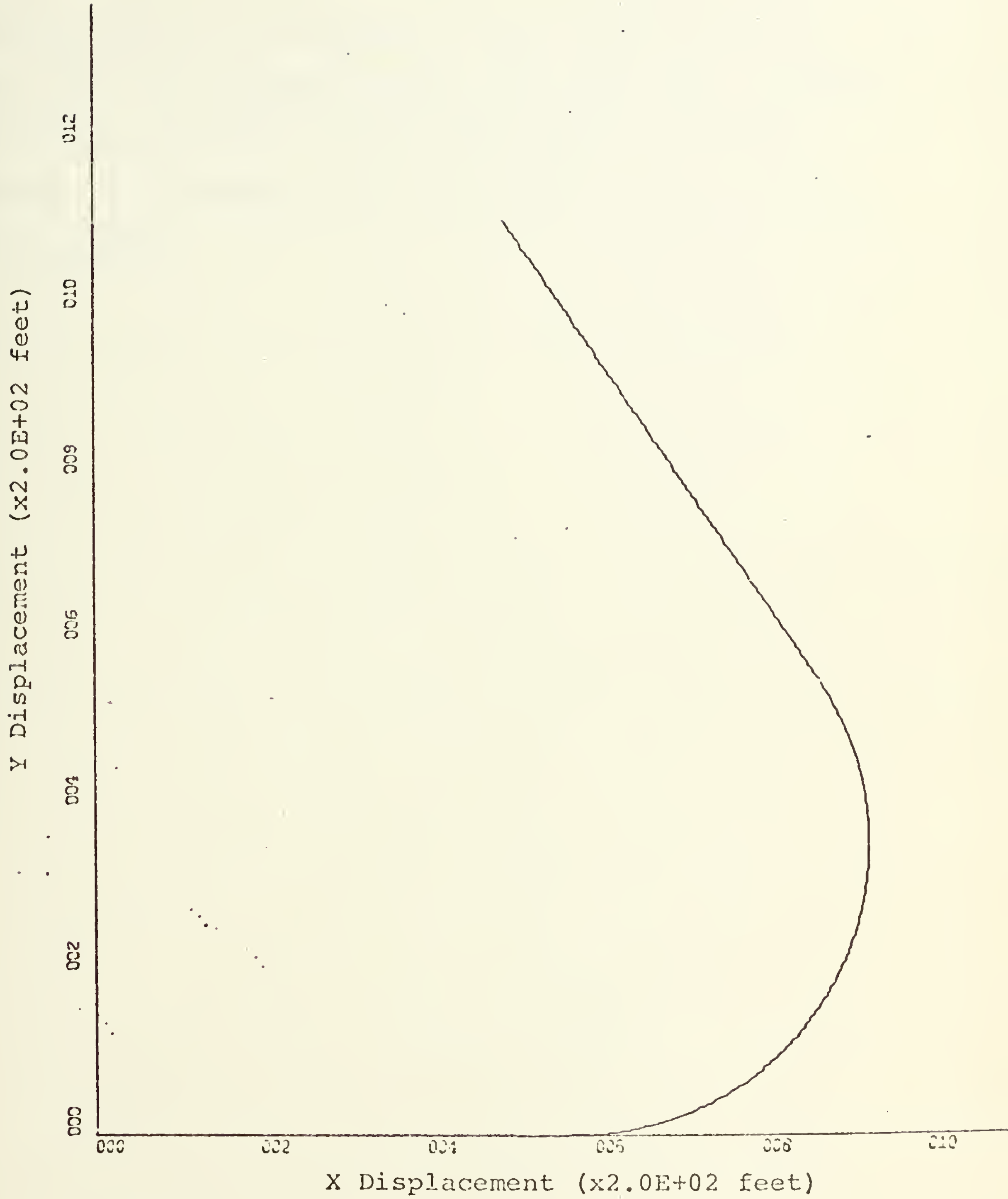
Fig. 20 Knot Turn: Roll Angle vs. Time

Figure 22



20 Knot Turn: Pitch Angle vs. Time

Figure 23



20 Knot Turn: X Y Displacement

be expected due to the nonlinearity of the system. The oscillation appears to be about 0.5 H_Z. This oscillation was not felt by the authors during craft test runs. However, it may not be sensed due to its high frequency and small amplitude. Unfortunately at this writing no accurate turn data is available.

VI. DISCUSSION AND EVALUATION OF SIMULATION RESULTS

A. DISCUSSION OF PRODUCT MOMENT OF INERTIA; I_{XZ}

No information has been available on the value of the product moment of inertia I_{XZ} for the XR-3. Therefore, throughout the XR-3 program development the moment of inertia I_{XZ} was set equal to zero. This decision had no effect on craft motions for calm water straight runs since craft motion was restricted to translational movement in the Z and X direction and rotation about the Y axis. However, when turns were attempted and waves off the bow were introduced, program instabilities were observed. These may be seen by referring to Figures 24, 25 and 26 which show that for small perterbations the craft reacts in a stable manner, but as the rudder angle increases toward 20 degrees the craft becomes unstable even though waves have not yet been introduced. A weight scaled value of I_{XZ} was obtained from the 100B input data set and was later used as a representative value for the XR-3.

B. 5 DEGREE TURNS WITH AND WITHOUT WAVES

In an attempt to verify conditions reported in Reference 8 for the 100B model, a 20 knot run with a 5 degree rudder turn with and without waves was introduced. The wavelength and wave height were scaled from Reference 8 according to relative craft size. Hence, a wavelength of 72 feet and a wave height of 0.16 feet were used with the XR-3 model. Wave amplitude and frequency of encounter are shown in Figure 29.

Figure 24
FIVE, FIFTEEN AND TWENTY DEGREE TURNS:
Roll Angle Versus Time, I_{xz} equal to zero

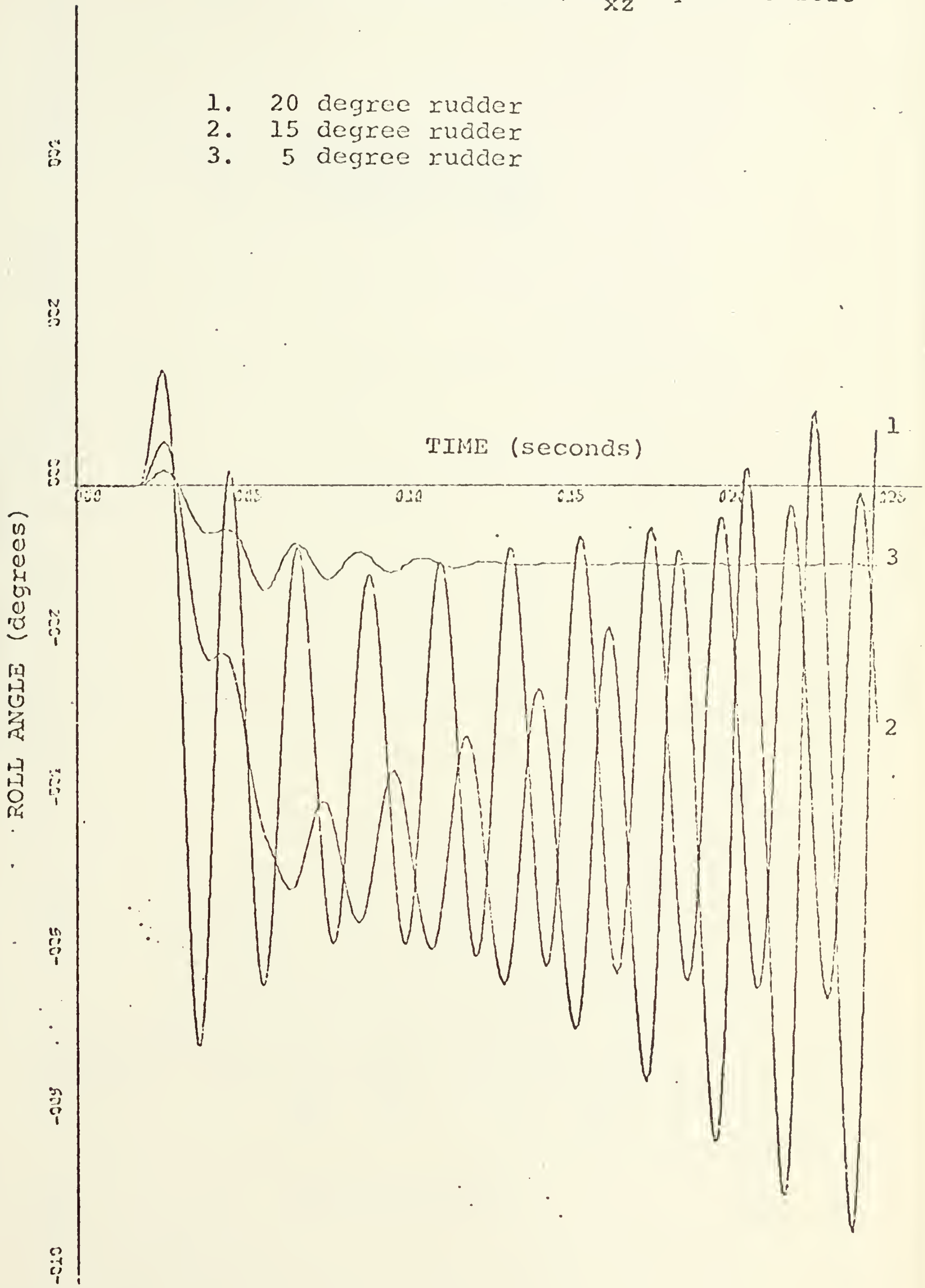


Figure 25
FIVE, FIFTEEN AND 20 KNOT TURNS:
Pitch Angle versus Time, I_{xz} equal to zero

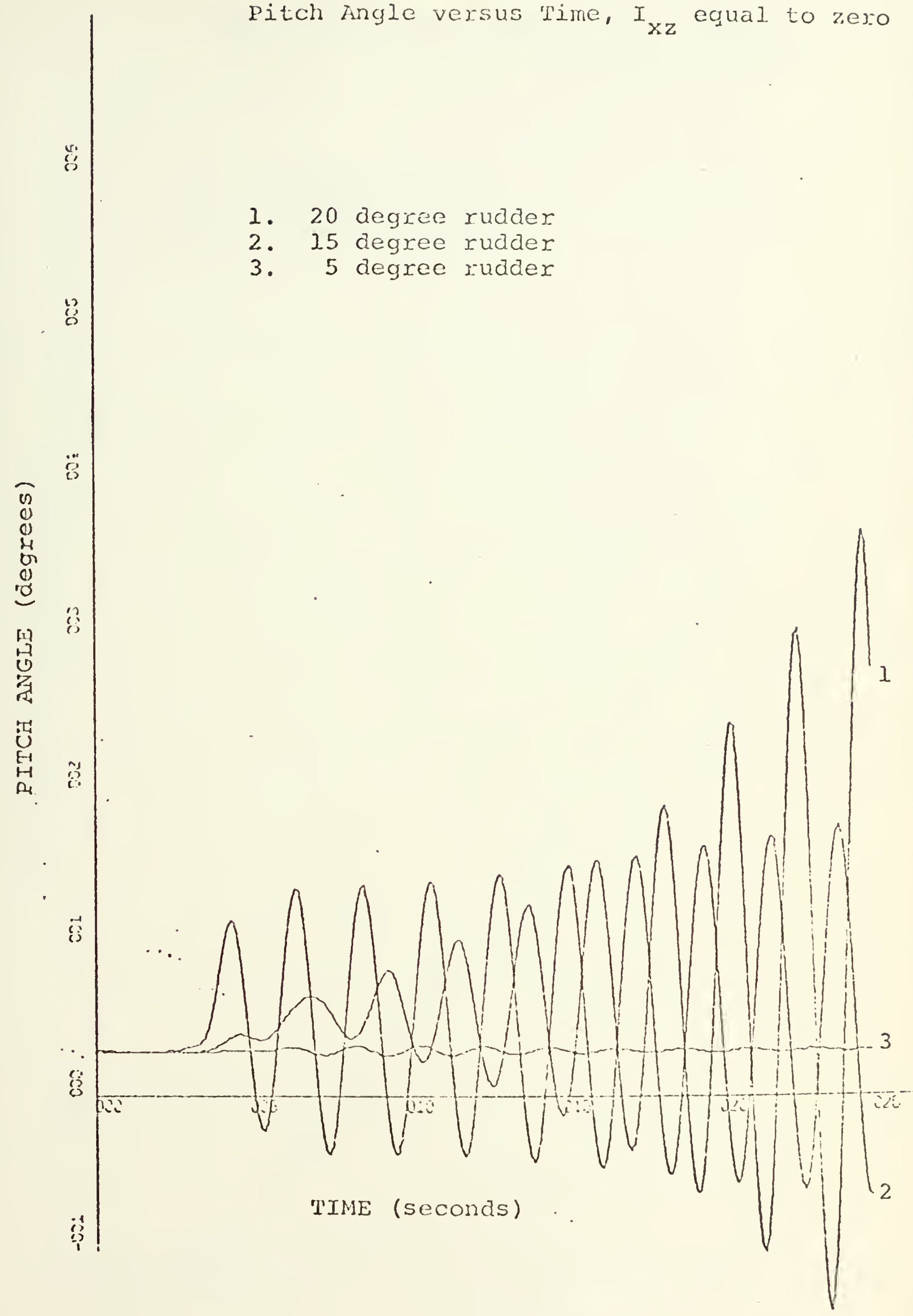
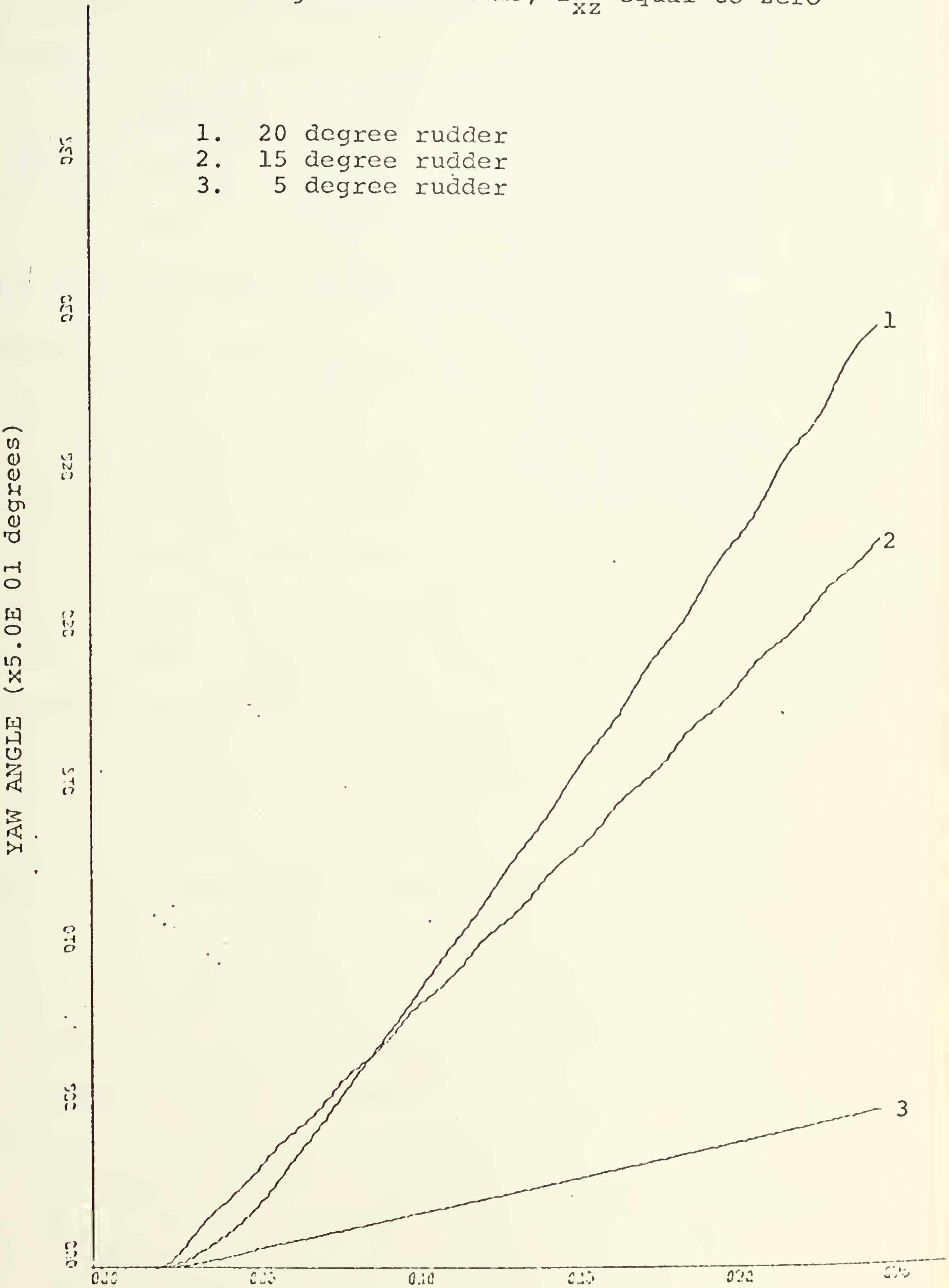


Figure 26

FIVE, FIFTEEN AND TWENTY DEGREE TURNS:
Yaw Angle versus Time, I_{xz} equal to zero



It is interesting to note that this same frequency can be seen in roll angle and pitch angle as shown in Figures 27 and 28. It is observed in Figure 27 that the amplitude of roll increases almost linearly as the wave front moves away from the ship's head, as would be expected for beam seas.

C. TURNS WITH 5, 15 AND 20 DEGREE RUDDER

Figures 31, 32, and 33 show the roll, pitch, and yaw motions produced by 5, 15, and 20 degree rudder turns at 20 knots in calm water with the product moment of inertia I_{XZ} inserted. In all cases, damping and system stability were observed. Similar turns made with I_{XZ} equal to zero revealed the presence of roll and pitch instability for large rudder angles. In both cases where 5 degree rudder turns were made the variations in the roll and pitch angles remained small and decayed to zero within 15 seconds or about 5 cycles.

D. COMPARISON OF SIMULATION AND MEASURED DATA

At the time of this writing measured pitch and roll data was not in a form suitable for definitive comparisons. However, recorded data of testcraft motion during turn maneuvers as shown in Figure 34 tend to validate the presence of damped roll and pitch oscillations which are also present in the simulated turns as shown in Figures 31, 32 and 33.

Measured and recorded plenum pressures tend to correspond with those calculated by the simulation program. This pressure appears to vary between 24-25 pounds per square

Figure 27
FIVE DEGREE TURN: Roll Angle Versus Time

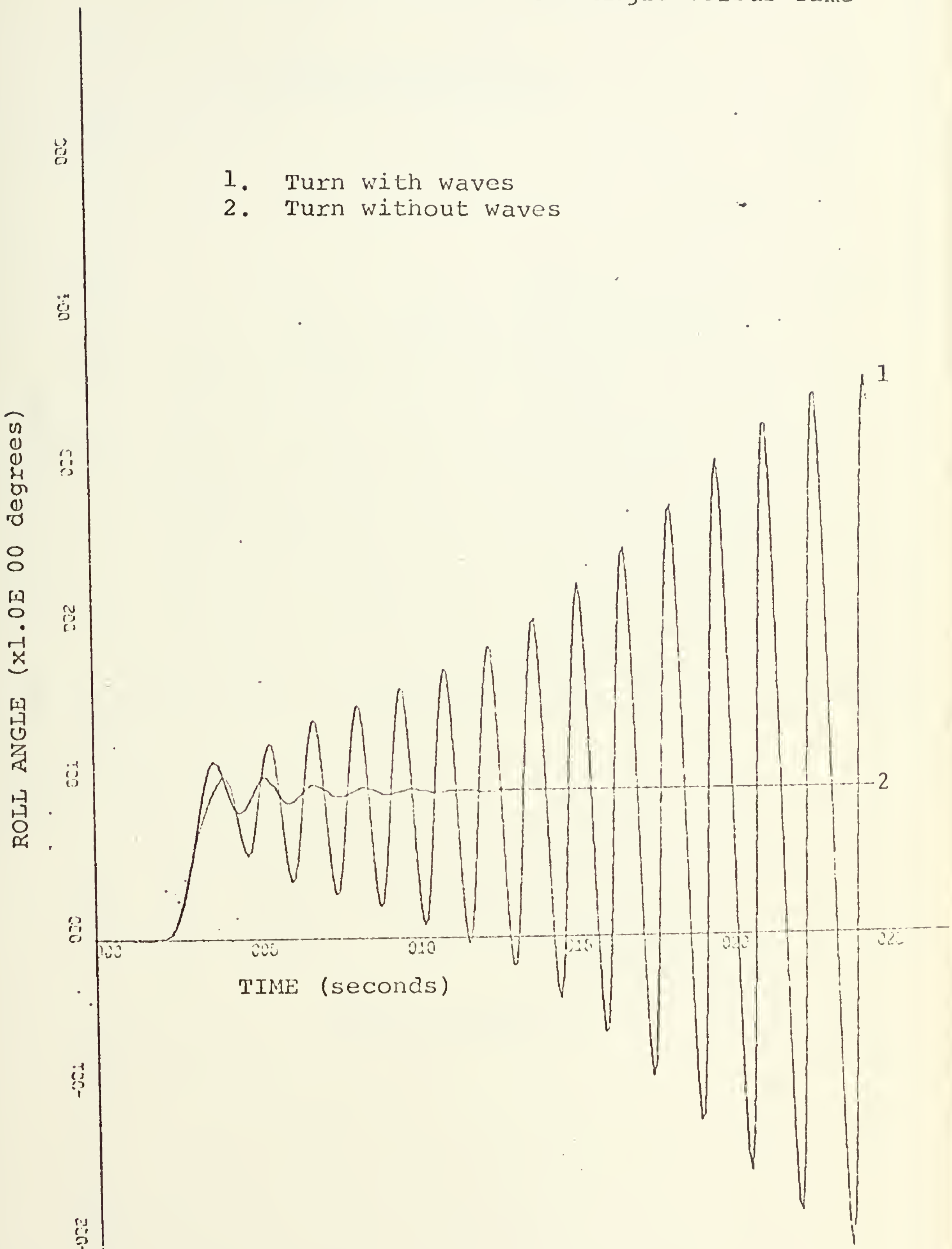


Figure 28

FIVE DEGREE TURN: Pitch Angle versus Time with and without waves

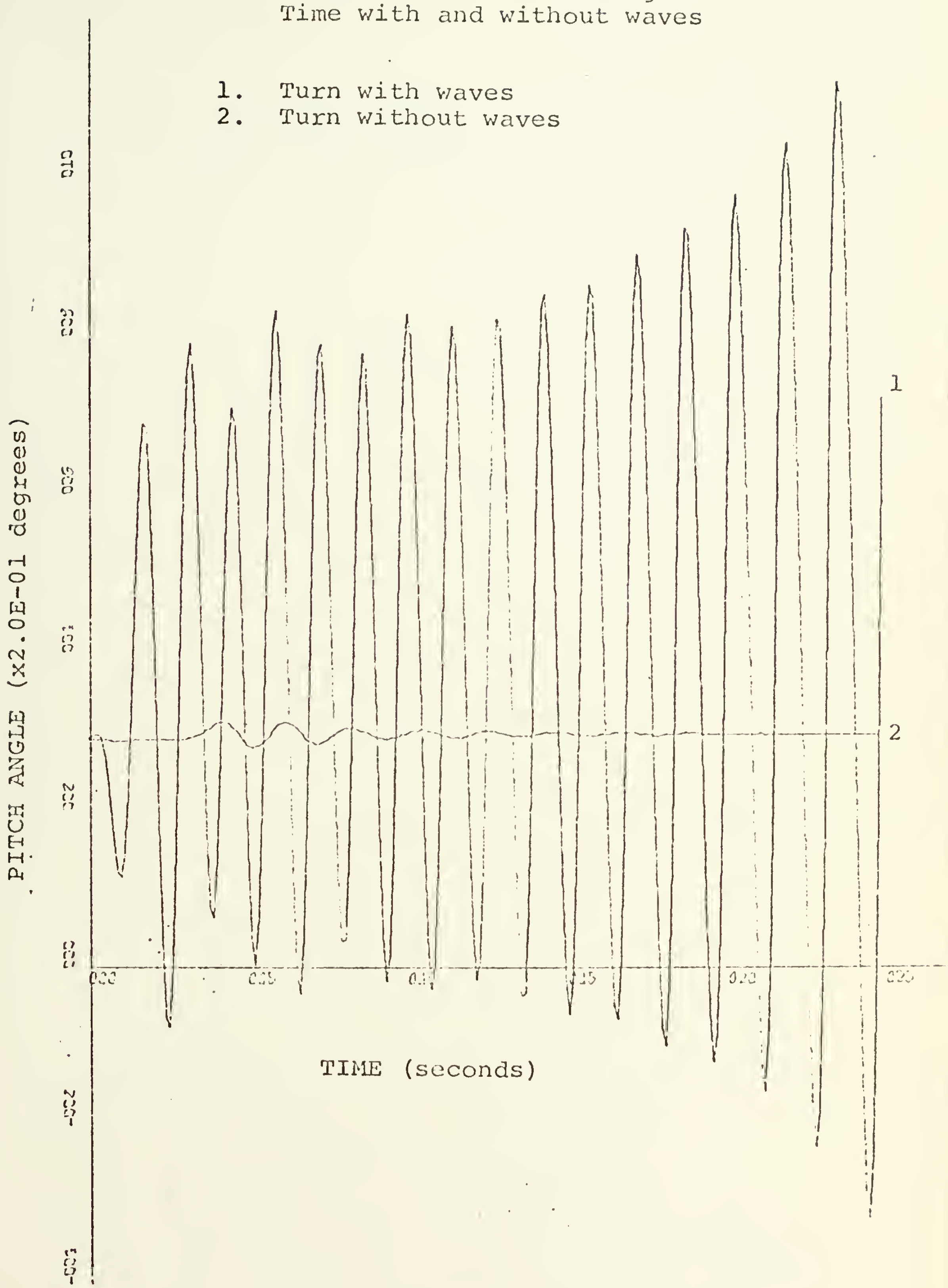


Figure 29
FIVE DEGREE TURNS: Wave Height versus Time

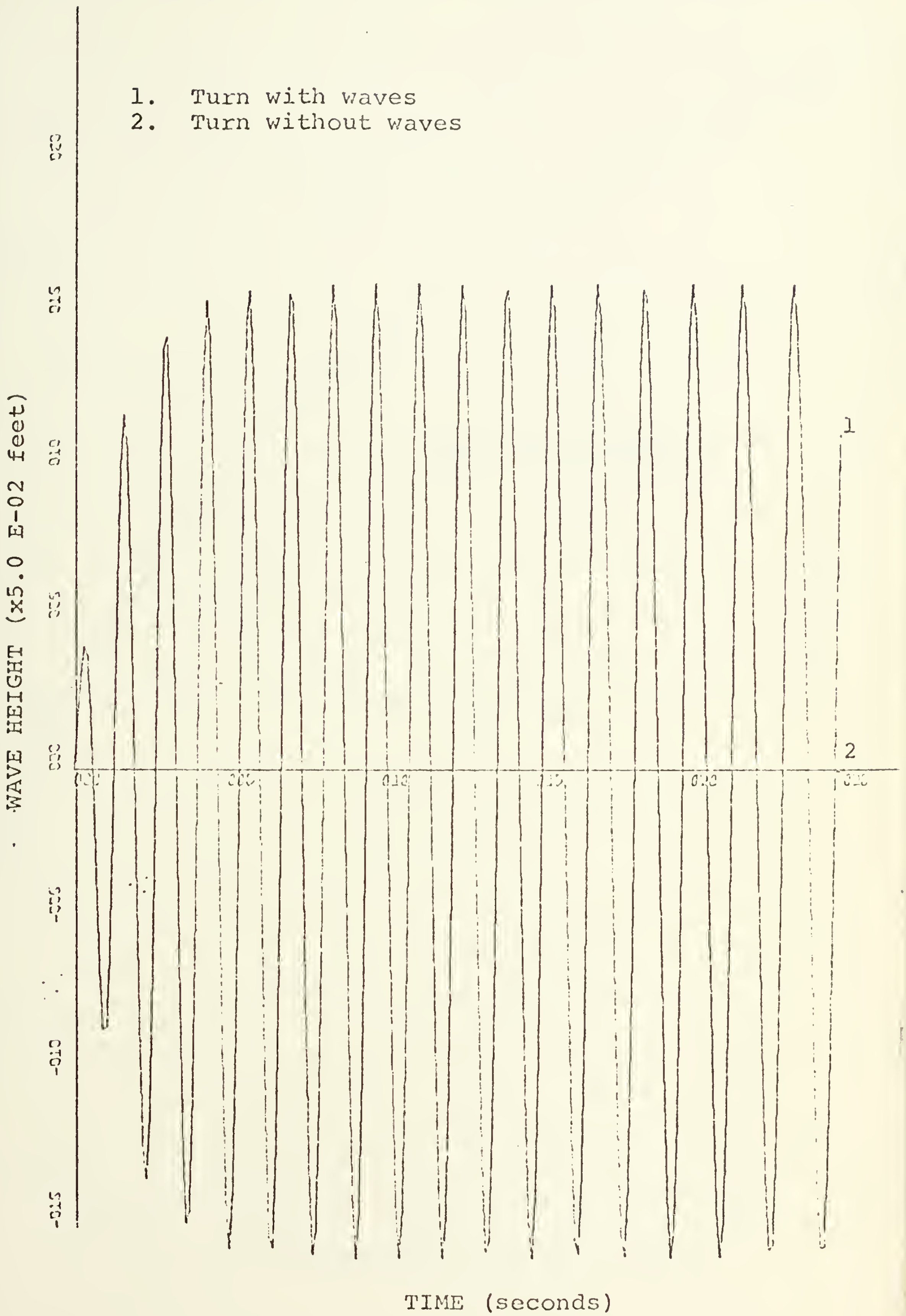


Figure 30

FIVE DEGREE TURN: X Displacement Versus Y Displacement

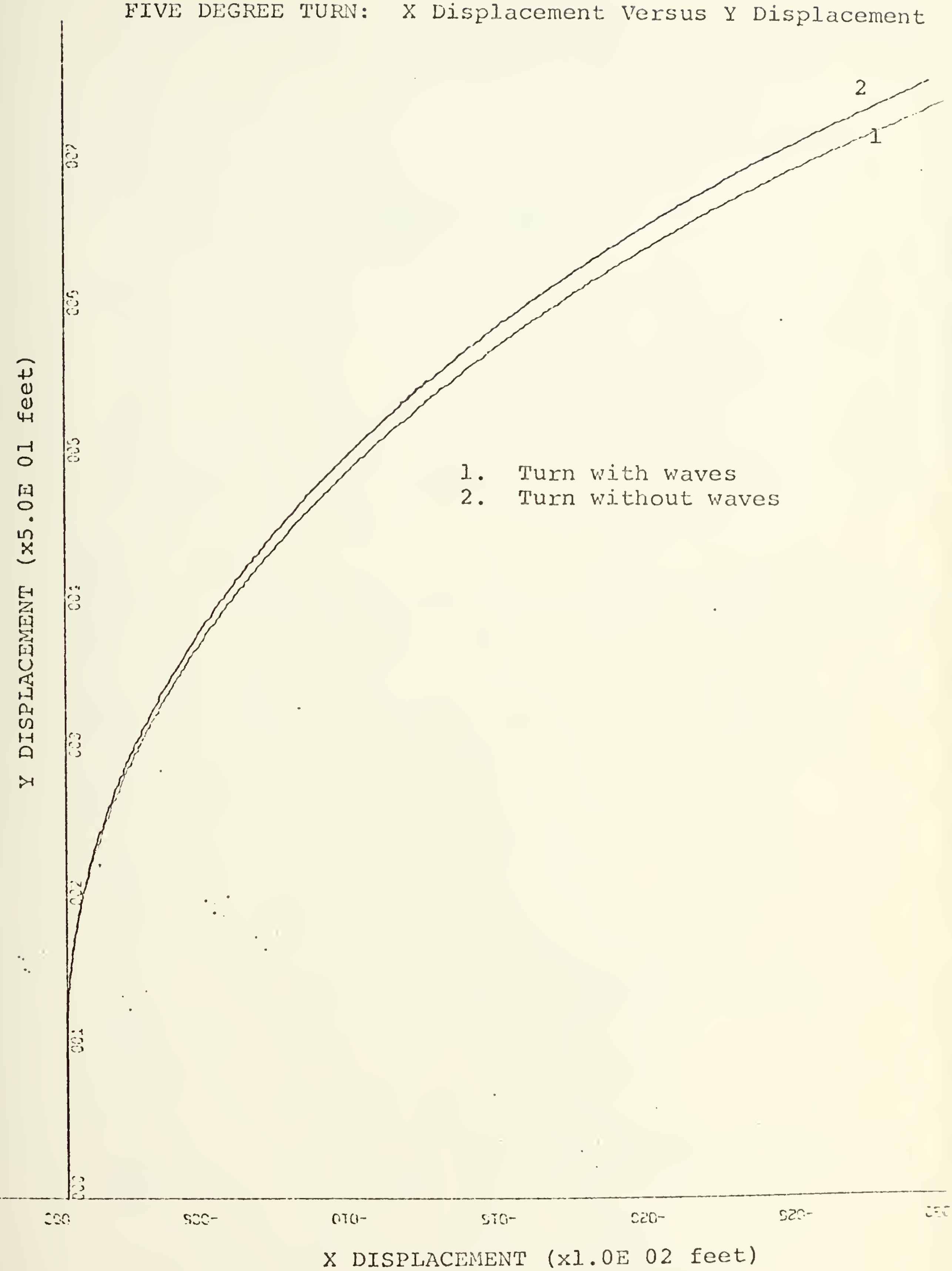


Figure 31

FIVE, FIFTEEN AND TWENTY DEGREE TURNS:
Roll Angle versus Time

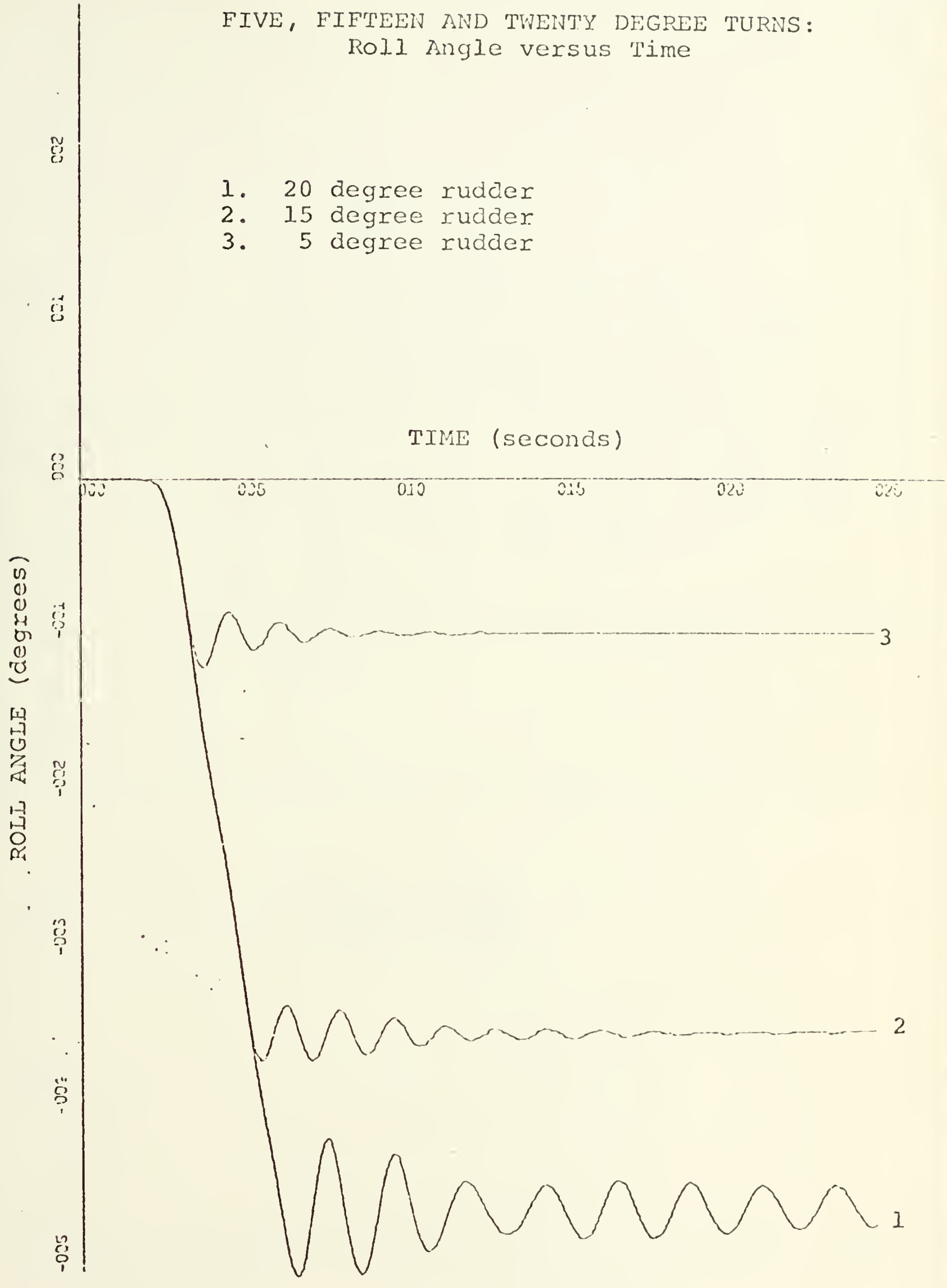


Figure 32

FIVE, FIFTEEN AND TWENTY DEGREE TURNS:
Pitch Angle Versus Time

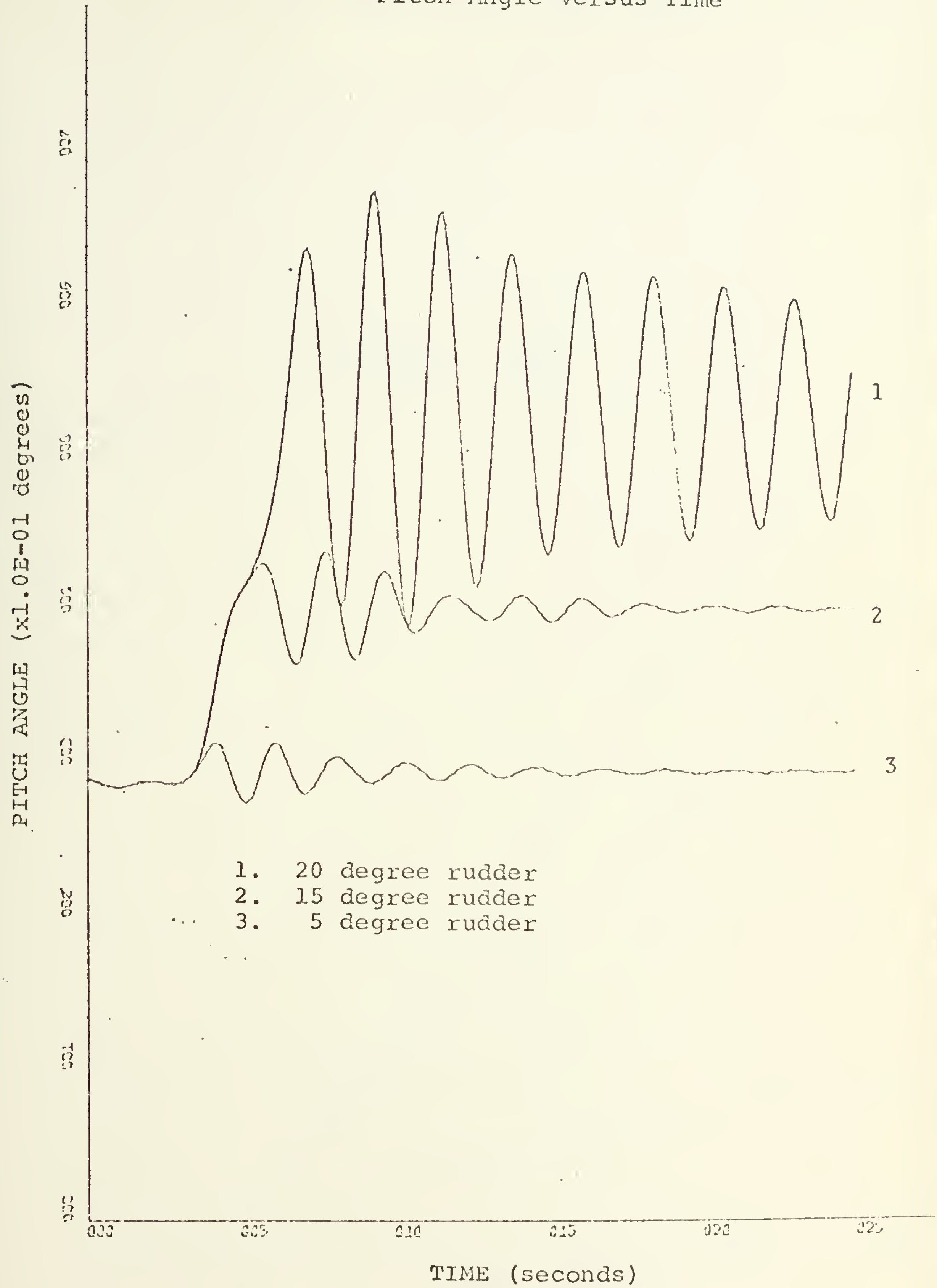
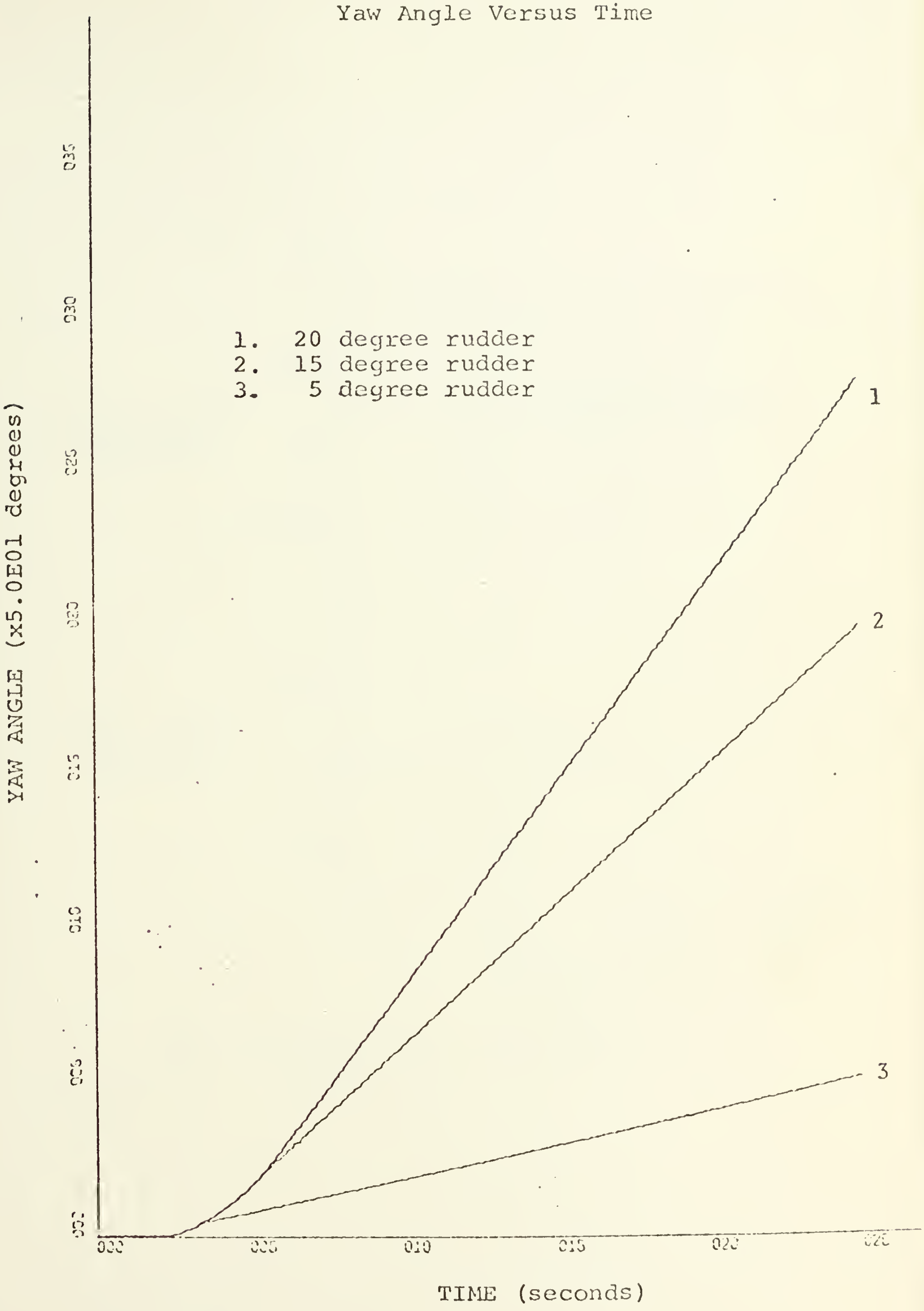
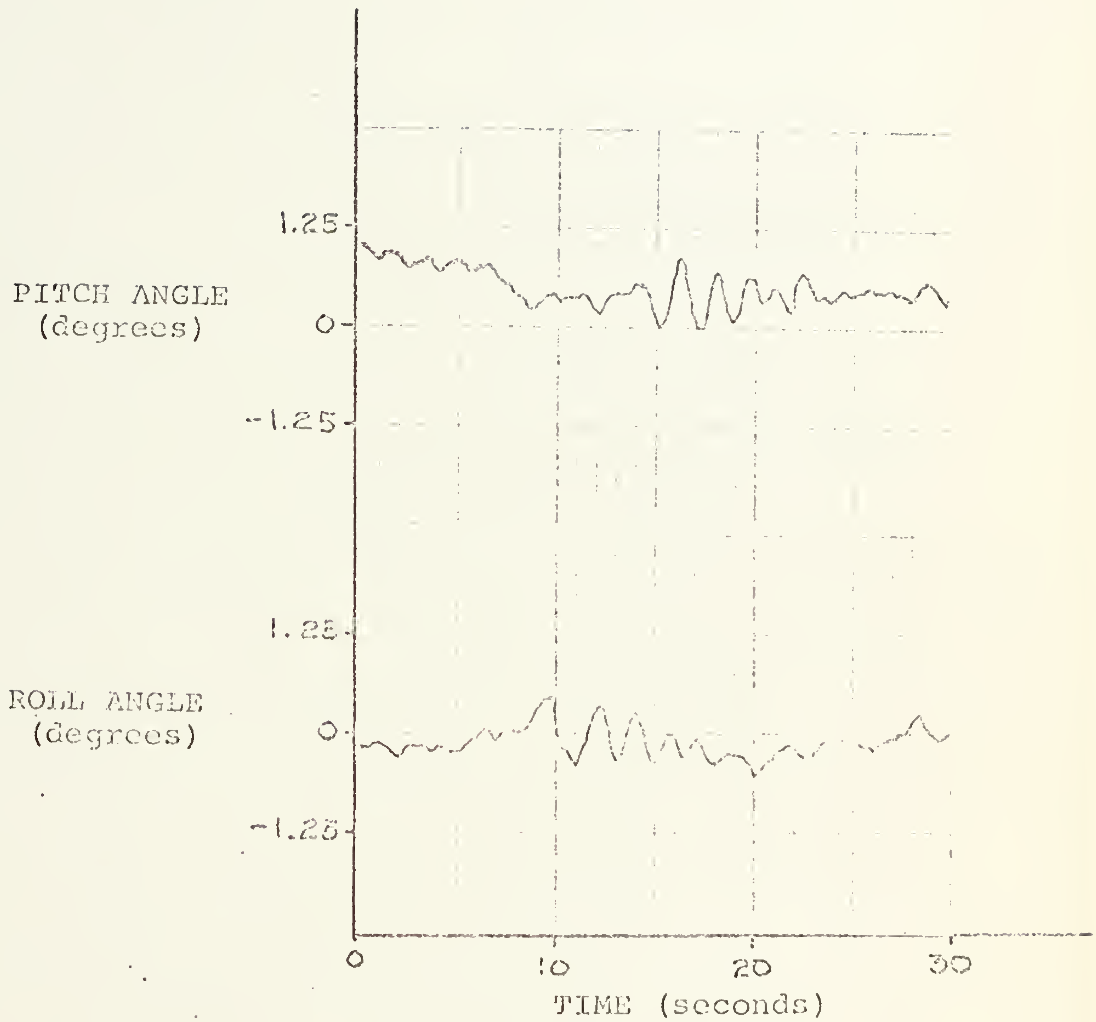


Figure 33

FIVE, FIFTEEN AND TWENTY DEGREE TURNS:
Yaw Angle Versus Time





PITCH AND ROLL ANGLE: Measured data
Figure 34

foot throughout all the various monitored craft motions.

VII. CONCLUSIONS AND RECOMMENDATIONS

The conversion of the L&M program from the 100B model to the smaller XR-3 model involved considerably more time and effort than was anticipated at the onset. A great deal of time was required for familiarization with the program, for providing a more useful output format and for adding plotting routines. Considerable effort was required to obtain the straight run, calm water trim conditions for various speeds. Plenum center of pressure movement with velocity was one of the more difficult problems encountered in obtaining the proper initial trim conditions. It is recommended that future investigators write an initial condition program to assist in reducing the time and effort required to arrive at the proper trim conditions.

Good agreement between measured and computed data for calm water straight runs was possible by the adjustment of the bubble drag coefficients, draft, bubble pressure and stern seal leakage. The measurement data for turning maneuvers could not be used for a check on the simulation in the form in which it is presently recorded. It is recommended that the recorded data be processed digitally and suitably reduced to a form useful for comparison with the L&M program output. Qualitative comparison of the XR-3 turn maneuver data however, has indicated that pitch and roll motion have a lightly damped response quite similar to the L&M program output. Much work remains to be done in checking

the accuracy of the computed transient response.

Additional qualitative checks were made on the computed XR-3 turn maneuvers by comparison with the 100B model response. The results indicated similar transient characteristics in which damping decreases as pitch or roll angle increase.

The simulation study of the XR-3 has demostrated the importance of the product moment of inertia I_{XZ} in maintaining stability in roll and pitch for rudder angles greater than 5 degrees. Future investigators should attempt to obtain an accurate value for I_{XZ}. This can be done by utilizing the discrete mass distribution option in the INCON Subroutine.

APPENDIX A

SES MOTIONS AND LOADS PROGRAM

USERS MANUAL

SES MOTIONS AND LOADS PROGRAM

USERS MANUAL

by

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Oceanics Incorporated

with modifications by

LCDR Don G. Leo and LT Richard Boncal U. S. Navy

TABLE OF CONTENTS

INTRODUCTION

The SES Motions and Loads Program is a Fortran IV program capable of calculating the time histories of the motions and loads of a surface effect ship operating in the on bubble mode in a seaway in six degrees of freedom. It is programmed in a "modular" fashion,i.e. each major element of the craft has its own subprogram. The input is in the form of basic data, i.e. sidewall offsets, seal geometry, fan map data points, etc. and enables the user to make a wide range of parametric changes to the particular craft being modeled by changing only the input data. The program has the capability of printing and/or plotting a wide range of variables as a function of time; such as forces and moments from each element, total craft forces, moments and accelerations, leakage gaps and flow rates, fan flow rates and power required, etc. The current program has been checked out and run on an IBM 360 computer (using version Release 20.6.) at the W. R. Church Computer Facility, NPS, Monterey, Ca.

This report is intended to be primarily a users manual for the program as it exists. The details of how one would rewrite various modules to reflect changes in the craft design are discussed extensively in Appendix A-A.

PROGRAM ORGANIZATION

Within a given run the program proceeds as follows. First the main program calls the input and initialization subroutine INCON. The program then proceeds to calculate the motion time histories by calling the various modular subroutines and the integration routine for as many time steps as is necessary to complete the run. During the course of the calculation the various subroutines will output those variables selected by the print option switches at the appropriate input print interval. In addition, data may be written on scratch files to be used for summarizing the output and doing bending moments and shear calculations. At the present time the Shears and Moments Subroutine has been removed, however, it may be reintroduced at any time with a minimum of changes.

When the run is completed, the program, depending on the options chosen, may then print and/or plot the output summary and proceed to do the bending moment and shear calculations. After these steps are completed the main program returns to INCON to read data for the next case.

The above procedure is repeated until all cases are finished.

PROGRAM REQUIREMENTS

As run on an IBM 360 computer under OS/360MVT version (Release 20.6), the program requirements are as follows;

	TOTAL CORE	TIME
Program length	$201{,}456_{10}$	NA
Core size required for execution	$250{,}000_{10}$	SEE BELOW

The total core required for a given step includes the program, system routines, data storage, etc. The time required to run a single case depends on the nature of the case and the length of time to be simulated. The ratio of required execution time to real time has been found to be as low as 1/3 for some calm water cases. Higher ratios occur where the transient curves are rather sharp.

The program currently uses the following FORTRAN Data Set Reference Numbers (Unit Numbers):

Unit Number	Usage
1	Scratch file for COLFIL plotting package.
2	Scratch file for lateral plane output summary
5	Input
6	Output
10-15	Sidewall Integral Table data (see Appendix A-C)

IBMF Intermediate file containing time histories required by bending moment calculations. The unit number IBMF is read in using the 01501 input card (see discussion of Input)

INPUT AND OUTPUT

The input for the program is handled by subroutine INCON and is discussed there. The output is controlled by the individual subprograms and is discussed separately there.

DESCRIPTION OF SUBPROGRAMS

Main Program

Discussion - The main program contains the logic for interconnecting the various subroutines. In addition, it compares the running value of time with the finish time, calculates the next value of time for printing after each print time, does some output, etc. The main program also contains the logic for the integration of the trajectory (x, y, ψ) by the trapazoidal rule.

Input - None

Output - The output from the main program is controlled by the print option switch ITRAJ. If the value of this switch is 1, the program will print the current values of the time and the craft velocities and displacements (angular and translational) as shown in the sample output at the end of the report.

Subroutine AEROD

Discussion - Subroutine AEROD calculates the aerodynamic forces and moments on the craft. The subroutine currently uses curve fits of the aerodynamic coefficients vs sideslip angle. Appendix A-A discusses how the program may be changed to input tabular data for the aerodynamic coefficients.

Usage - CALL AEROD

Input - The input data for AEROD is controlled by block 10 of subroutine INCON and is discussed there.

Output - The output from AEROD is controlled by print option switch IAEROD. If this switch is 1, the program will print the total forces and moments calculated as shown in the sample output at the end of the report.

Subroutine BOWSL

Discussion - Subroutine BOWSL calcualtes the forces and moments due to the bow seal and the leakage flow rate associated with any gaps which open up under the various seal stations.

Usage - CALL BOWSL

Input - The input data for BOWSL is controlled by blocks 3, 6, and 17 of subroutine INCON and is discussed there.

Output - The output from BOWSL is controlled by print option switch IBOWSL. If this switch is 1, the program will print the gaps and wetted lengths at the various stations on the bowseal as well as the total forces and moments due to the bowseal. A sample print point is given in the sample output at the end of the report.

Subroutine COLFIL

Discussion - Subroutine COLFIL is used to format the program output. It can provide up to 16 variables listed in two tabular summaries of 8 variables each. The subroutine has a plotting package that permits use of either the print plot or calcomp (continuous line) option. Multiple curves may be plotted and up to 10 graphs may be drawn on each run. Print switches control the printing by each subroutine of its forces and moments. This option is very useful in debugging the program. Normally it provides too much output and is too cumbersome.

Usage - CALL COLFIL

Input - The input is controlled by the control card with the control tag 00104 and is discussed in the description of Subroutine INCON in the block 1 control card section. Additional input required for the plotting package is contained in the Users Manual for the COLFIL routine.

Output - For output format consult the COLFIL plotting package users manual.

Subroutine DMINV

<u>Discussion</u> - Subroutine DMINV is a matrix inversion package used for inverting the mass matrix. The method used is the standard Gauss-Jordan technique. The determinant of the matrix is also calculated. If the determinant is zero the matrix is singular and the program will stop (see Appendix A-B Abnormal Termination Messages).

<u>Usage</u> - CALL DMINV (A, N, D)

<u>Description of Parameters</u>

A = The input matrix, destroyed in computation and replaced by resultant inverse

N = The order of matrix (maximum = 6)

D = The resultant determinant of the matrix

<u>Input</u> - None

<u>Output</u> - None

Subroutine FAN

Discussion - Subroutine FAN is used to calculate the inflow to the plenum, stern seal, and bowseal from the fans for a given pressure differential across the fans. The subroutine uses tabular data and allows for changes in fan speed as well as the number of fans. Fan speed changes are currently handled by using the fan scaling laws rather than reading data as a function of fan speed.

Usage - CALL FAN

Input - The input for subroutine FAN is controlled by block 19 of subroutine INCON and is discussed there.

Output - The output from FAN is controlled by print option switch IVEL. If this switch is 1, the program will print the flow rates and pressure differentials across the bow seal, cushion and stern seal fans, as well as the total fan horsepower required as shown in the sample output at the end of the report.

Function FG1

Discussion - The purpose of FG1 is to perform the task of evaluating a tabular function y = f(x). The procedure used is linear interpolation between data points. If the input value of the independent variable does not fall in the range of its input tabular values the appropriate table extreme is held. The function y must be single valued and the tabular values for the independent variable must be stored in ascending order i.e. XTAB(J) < XTAB(J+1). The increment between tabular values need not be constant.

Usage - Y = FG1 (X, N, XTAB, YTAB, IMEM)

Description of Parameters

- Y = The output value of the tabular function
- X = The value of the independent variable to be used to evaluate the function y = f(x)
- N = The number of elements in the XTAB and YTAB arrays
- XTAB = The name of the array that contains the values of the independent variable in ascending order
- YTAB = The name of the array that contains the values of the dependent variable corresponding to the values of the independent variable stored in XTAB
- IMEM = Dummy variable used to store location of last entry into table, to be used as initial point of search at next entry

Input - None

Output - None

Subroutine FORIT

Discussion - Subroutine FORIT is used to obtain a Fourier analysis of a periodically tabulated function. It computes the coefficients of the desired number of terms of the Fourier series $f(x) = a(0) + \sum_{k=1}^{M} (a(k)\cos kx + b(k)\sin kx)$, to approximate the given set of periodically tabulated values of a function.

Usage - CALL FORIT (FNT, N, M, A, B, IER)

Description of Parameters

FNT = Vector of tabulated function values of length 2N+1

N = The interval such that 2N+1 points are taken over the interval $(0, 2\pi)$. The spacing is thus $2\pi/(2N+1)$. N must be greater than or equal to M

M = Maximum order of harmonics to be fitted. M must be greater than or equal to zero

A = Resultant vector of Fourier cosine coefficients

B = Resultant vector of Fourier sine coefficients

IER = Resultant error code where:

IER=0	No error
IER=1	N less than M
IER=2	M less than 0

Input - None

Output - None

Subroutine INCON

Discussion - Subroutine INCON contains the logic for the reading of all input data, the initialization of variables and for the initiation of new cases. The subroutine is programmed so that the input data is non-structured i.e. there is no set order of input cards from one read statement to another. However, a given read statement may have more than one input card. In runs with multiple cases, only those input parameters which are to be changed for the new case need be read in.

Usage - CALL INCON

Input - The input logic is subdivided into twenty-two "blocks." Each block being for a particular subroutine or function e.g. stern seal, sidewall, etc. Switching to the proper input block is done by means of a control tag on the input cards. Once control has been transferred to a particular block additional input may be read by specific format statements if necessary, however, the card which contains the control tag may also be used to input up to seven variables for the selected block. The format of the input card used for switching is as follows:

Column	Format	Entry
1-3	I3	control tag
4-5	I2	option tag
6-75	7F10	input variables (if any)

The control tag used to transfer control to the appropriate block is of the form OMN where M and N are integer constants, i.e., if the control tag is 015 the program will go to statement 1500.

The option tag is loaded into a variable called IOPT and allows different branches of logic within a given input block. If no branches are used within the input block the option tag may be zero.

The input variables are stored in an array called TEMP and may be set to a given parameter by using an arithmetic replacement statement in the appropriate block (see various blocks in attached listing for examples).

Example: When read, a card of the form

```
Column      3  5           15               25        35        80
            ↓  ↓            ↓                ↓         ↓         ↓
          017 02    3.5          blank            1.0      blank
```

will transfer control to statement 1700. Within statement 1700 the logic might look as follows

```
      1700  CONTINUE
            GO TO (1710, 1720), IOPT
      1710  A = TEMP (1)
            B = TEMP (2)
            GO TO 10
      1720  C = TEMP (1)
            D = TEMP (2)
            E = TEMP (3)
            GO TO 10
```

In the above example the option switch IOPT is 02 and will cause the program to go to statement 1720 which will then set C=3.5, D=0.0, E=1.0 and then will return to statement 10 which is the read statement for the input cards.

The various input blocks as currently programmed are as follows:

Block Number	Function
1	Executive input (time steps, print switches, option switches, etc.)
2	Mass and inertial input
3	Craft geometric input
4	Sidewall input
5	Stern seal input
6	Bow seal input
7	Plenum input
8	Propulsion geometry input
9	Rudder input
10	Aerodynamic input
11	Wave input
12	Initial conditions
13	End of case indicator
14	End of run indicator
15	Not used
16	Thrust, rudder motion input
17	Bow and stern seal pressure input
18	Title card
19	Fan map input

Card	Columns	Format	Entry
1	1-5	I	00101 - control tag and option
	6-15	F	Start time (generally zero), sec.
	16-25	F	Finish time, sec.
	26-35	F	Initial integration time step, sec.
	36-45	F	Print interval, sec.
	46-55	F	Print start time, sec.

Option tag = 2 Print switches (if=1 print if=0 no print)

Card	Columns	Format	Entry
1	1-5	I	00102 - control tag and option
2	5	I	IACCEL, print switch for lateral acceleration and integration time step
	10	I	IVEL, print switch for subroutine FAN
	15	I	ITRAJ, print switch for main program
	20	I	ISIDWL, print switch for subroutine SIDEWL
	25	I	IBOWSL, print switch for subroutine BOWSL
	30	I	ISTNSL, print switch for subroutine STNSL
	35	I	IWAVES, print switch for subroutine WAVES
	40	I	IRUD, print switch for subroutine RUDDER

Option tag = 2 (Continued)

Card	Columns	Format	Entry
2 (Cont.)	45	I	IPROP, print switch for subroutine PROP
	50	I	IAEROD, print switch for subroutine AEROD
	55	I	IRHS, print switch for subroutine RHS

Option tag = 3 Integrator Tolerances

Card	Columns	Format	Entry
1	1-5	I	00103, control tag and option
2	1-2	I2	Number of integrators to be used (maximum of 15)
	3-4	I2	Control tag for integration procedure
3, 4...	1-80	8F10	Integrator error tolerance, one per integrator

Note: The usual procedure for selecting integrator tolerances is to choose values on the order of 10^{-5} to 10^{-8}. However, for each new craft the following procedure is used; make a run with a given set of tolerances; halve the tolerances and rerun. If the results do not change drastically, try doubling the original tolerances and running. As changes are noted in the integrator outputs (i.e. craft velocities, etc.), hold the tolerances for those integrators fixed and vary the others until the largest tolerances possible are obtained. Once

chosen for a given craft the tolerances rarely have to be changed. A control tag (JQQ in the program) is used to select integration procedure. A blank provides the original R-K., procedure. A"one" provides a fixed step size runga-kutta procedure that could be useful in selecting integrator tolerances. A "two" provides runga-kutta variable step size, but does not print out the step varying procedure. Only the minimum stepsize is output.

Option tag = 4 Tabular Summary of Output

Card	Columns	Format	Entry
1	1-5	I	00104, control tag and option
2	5	I	Print switch for summary one 1 = print, 0 = no print
	10	I	Print switch for summary two 1 = print, 0 = no print

Option tag = 5 Program Option Switches

Card	Columns	Format	Entry
1	1-5	I	00105, control tag and option
	6-15	F	Switch for lateral plane motions 1 = only lateral plane motions 0 = six degrees of freedom
	16-25	F	Switch for constant speed 1 = surge equation not used 0 = surge velocity allowed to vary

Card	Columns	Format	Entry
	26-35	F	Switch for trim 1 = thrust varied to give proper speed. If this option is selected, then there must be input in Block 16 an estimate of thrust and a 0.0 for the number of data points. 0 = thrust as input

Block 2 - Mass and Inertial Input

Option tag = 1   Summary Mass Properties Card

Card	Columns	Format	Entry
1	1-5	I	00201 - control tag
	6-15	F	Total craft weight, pounds
	16-25	F	Longitudinal center of gravity, feet forward of transom
	26-35	F	Vertical center of gravity feet above baseline (keel)
	36-45	F	I_{xx}, mass moment of inertia about x axis, slug - ft.^{2}
	46-55	F	I_{yy}, mass moment of inertia about y axis, slug - ft.^{2}
	56-65	F	I_{zz}, mass moment of inertia about z axis, slug - ft.^{2}
	66-75	F	I_{xz}, mass moment of inertia about xz axis, slug - ft.^{2}

Note: If this option is used, shears and moments will not be calculated correctly.

Option tag = 2 Discrete Mass Distribution Cards

Card	Columns	Format	Entry
1	1-5	I	00202 - control tag
2, 3, 4...	1 -10	F	Discrete weight, pounds
	11-20	F	Longitudinal c.g., feet forward of transom
	21-30	F	Transverse c.g., feet to starboard
	31-40	F	Vertical c.g., feet above baseline (keel)
Last card	1-10	F	-1.0 - control tag

The mass distribution is specified by discrete weights at various locations with one card used for each weight. Symmetry about the longitudinal center-plane is assumed, so that only weights on the starboard side, with atransverse location greater than zero should be specified. Thus, the total weight on the input cards is one half the total craft weight. The last card is used to signal the end of the discrete weights. The maximum number of discrete weights is 201.

Block 3 Craft Geometric Input

No option tags

Card	Columns	Format	Entry
1	1-5	I	00300 - control tag
	6-15	F	Number of stations on port sidewall

Card	Columns	Format	Entry
	16-25	F	Number of stations on starboard sidewall
	26-35	F	Number of stations on bow seal
	36-45	F	Number of stations on stern seal
	46-55	F	Total craft length, ft.

Note: The maximum number of stations is 11 for each element. The program will automatically subdivide the element into N-1 sections (N is the number of stations) and calculate the x and y coordinates of each station.

Block 4 Sidewall Input

Option tag = 1 Sidewall Input

Card	Columns	Format	Entry
1	1-5	I	00401 - control tag and option
	6-15	F	y distance from centerline to sidewall, ft.
1	16-25	F	Average wetted length of side-wall, ft.
	26-35	F	Leakage orifice coefficient of sidewall
	36-45	F	Cross-flow drag coefficient of sidewall
	46-55	F	Average beam of sidewall, ft.

Note: Under this option tag the program will also read the sidewall integral table file stored on Unit 10.

Block 5 Stern Seal Input

No option tags

Card	Columns	Format	Entry
1	1-5	I	00500 - control tag
1	6-15	F	x coordinate of seal hinge, ft. forward of transom
	16-25	F	z coordinate of seal hinge, ft. above keel
	26-35	F	Base leakage area, sq. ft.
	36-45	F	Seal leakage orifice coefficient
	46-55	F	Angle between leading edge of seal and craft vertical, deg.
	56-65	F	Pressure differential between seal bag and bubble, psf
	66-75	F	Length of leading edge of seal, ft.

Block 6 Bow Seal Input

No option tags

Card	Columns	Format	Entry
1	1-15	I	00600 - control tag
	6-15	F	x coordinate of seal hinge, ft. forward of transom
	16-25	F	Seal leakage orifice coefficient
	26-35	F	Pressure differential between seal bag and bubble, psf
	36-45	F	Z coordinate of the seal hinge above keel, feet
	46-55	F	Angle between leading edge of seal and craft vertical, deg.
	56-65	F	Length of the leading edge of the seal, feet
	66-75	F	Base leakage area, ft.

Block 7 Plenum Input

Option tag = 1 Plenum Geometry

Card	Columns	Format	Entry
1	1-5	I	00701 - control tag and option
1	6-15	F	Plenum length at water surface, ft.
	16-25	F	Plenum width at water surface, ft.
	26-35	-	Not used at present
	36-45	F	Plenum width at deck, ft.
	46-55	F	Plenum length at deck, ft.
	56-65	F	x coordinate of center of pressure, ft., forward of transom
	66-75	F	Plenum average height

Option tag = 2 Critical Froude Number

Card	Columns	Format	Entry
1	1-5	I	00702 - control tag and option
	6-15	F	Froude number corresponding to hump speed

Block 8 · Propulsion Input

Option tag = 1 Basic Data

Card	Columns	Format	Entry
1	1-15	F	00801 - control tag and option
	6-15	F	x coordinate of propeller center, ft. forward of transom
	16-25	F	y distance from centerline to propeller center, ft.
	26-35	F	z coordinate of propeller, ft. above keel

Block 9 Rudder Input

Option tag = 1 Rudder Geometry

Card	Columns	Format	Entry
1	1-5	I	00901 - control tag and option
	6-15	F	x coordinate of centroid of rudder, ft. forward of transom
	16-25	F	y distance from centerline to rudder centroid, ft.
	26-35	F	z coordinate of centroid of rudder, ft. above keel
	36-45	F	Rudder span, ft.
	46-55	F	Rudder aspect ratio
	56-65	F	Rudder area, sq. ft.
	66-75	F	Average Thickness ratio of rudder section

Block 10 Aerodynamic Input

No option tags

Card	Columns	Format	Entry
1	1-5	I	01000 - control tag
	6-15	F	Reference length, ft.
	16-25	F	Reference width, ft.

Note: The reference length and width are those used to nondemensionalize the wind tunnel data used in the program.

Block 11 Waves Input

Option tag = 1 Amplitude vs. frequency

Card	Columns	Format	Entry
1	1-5	I	01101 - control tag and option
	6-15	F	Number of wave components, maximum of 10
	16-25	F	Initial wave heading relative to craft headings (180° = head seas), deg.
2, 3, 4...	1-10	F	Wave frequency, rad./sec.
	11-20	F	Wave amplitude, ft.

Option tag = 2 Amplitude vs. wave length

Card	Columns	Format	Entry
1	1-5	I	00102 - control tag and option
	6-15	F	Number of wave components, maximum of 10
	16-25	F	Initial wave heading relative to craft heading (180° = head seas), deg.
2, 3, 4...	1-10	F	Wave length, ft.
	11-20	F	Wave amplitude, ft.

Note: The program constructs irregular seas by adding together a series of regular wave components with appropriate distribution of amplitude and frequency. To run a regular sea case, the number of wave components should be equal to 1. If the number of waves is equal to zero (calm water) no additional data (cards 2, 3, 4...) should appear.

Block 12 Initial Conditions

No option tags

Card	Columns	Format	Entry
1	1-5	I	01200 - control tag
	6-15	F	Initial speed, knots
	16-25	F	Initial pitch angle (positive-nose up), deg.
	26-35	F	Initial draft at the center of gravity, inches
	36-45	F	Initial bubble gage pressure, psf

Block 13 End of Case

No option tags

Card	Columns	Format	Entry
1	1-5	I	01300 - control tag

Note: This card is used to signal the end of data for a given case. The program will now initialize all required variables and will start the calculation of the time history.

If the program reads two consecutive 01300 cards with no data between, the job will be stopped rather than repeat the previous case.

Block 14 End of Run

No option tags

Card	Columns	Format	Entry
1	1-5	I	01400 - control tag

Note: This card is used to signal the end of the run. When encountered the program will print out the message:

COMPLETED ALL RUNS

and will then stop.

Block 16 Thrust and Rudder Input

Option tag 1 = STB Thrust input

Card	Columns	Format	Entry
1	1-5	I	01601 - Control tag and option
	6-15	F10	Value of constant thrust for the starboard screw if variable thrust is not desired
	16-25	F10	Number of data points in the thrust map. Left blank if constant thrust is used.
	26-35	F10	Side thrust coefficient
2,3..	1-80	8F10	Data points for the independent variable, time in ascending order.
	1-80	8F10	Corresponding data points for the dependent variable.

Option tag 2 = Port thrust input

Card	Columns	Format	Entry
1	1-5	I	01602 - Control tag and option
	6-15	F10	As above for the port screw.
	16-25	F10	" " " " " "
	26-35	F10	" " " " " "
2,3..	1-80	8F10	" " " " " "
	1-80	8F10	" " " " " "

Option tag 3 = Rudder motion input

Card	Columns	Format	Entry
1	1-5	I	01603 - Control tag and option
	6-15	F10	Value of rudder if constant rudder is desired
	16-25	F10	Number of data points of the rudder map. Left blank if constant rudder is desired.
2,3..	1-80	8F10	Values of the independent variable time in ascending order.
	'1-80	8F10	Corresponding values of rudder angle in degrees. Note: Positive rudder angle is right rudder.

Block 17 Bow and Stern Seal Pressure Differences Input

Option tag 1 = Bow seal

Card	Columns	Format	Entry
1	1-5	I	01701 - Control tag and option
	6-15	F	Number of data points for the bow seal

Card	Columns	Format	Entry
2,3..	1-80	8F10	Time points in ascending order
6,7..	1-80	8F10	Corresponding differences in bow seal pressures

Block 17 shall be left blank if a constant pressure is desired. That constant shall be input in Block 5 and 6. However, one seal may be held constant and the other varied.

Option 2 = Stern seal

Card	Columns	Format	Entry
1	1-5	I	01702 - Control tag and option
	6-15	F	Number of data points for the stern seal
2,3..	1-80	8F10	As for option 1, for the stern seal
6,7..	1-80	8F10	As for option 1, for the stern seal

Block 18 Title card

No option tags

Card	Columns	Format	Entry
1	1-5	I	01800 - control tag
2	1-80	20A4	Alphanumeric data to be printed as title in input summary

Block 19 Fan Maps

Option tag = 1 Bow Seal Fans

Card	Columns	Format	Entry
1	1-5	I	01901 - control tag and option
	6-15	F	Number of bow seal fans
	16-25	F	Speed of bow seal fans, rpm
	26-35	F	Number of data points (maximum of 25)
	36-45	F	If this is a 1.0 then the following data points are read. If left blank no further read takes place.
2,3..	1-80	8F10	Tabular value of fan pressure differential, psf.
After last pressure data card	1-80	8F10	Corresponding volumetric flow rate, cu.ft./sec.

Option tag = 2 Cushion Fans

Card	Columns	Format	Entry
1	1-5	I	01902 - control tag and option
	6-15	F	Number of cushion fans
	16-25	F	Speed of cushion fans, rpm
	26-35	F	As option 1 above
2,3..	1-80	8F10	Tabular values of fan pressure differential, psf
After last pressure data card	1-80	8F10	Corresponding volumetric flow rate.

Option tag = 3 Stern Seal Fans

Card	Columns	Format	Entry
1	1-5	I	01903 - control tag and option
	6-15	F	Number of stern seal fans
	16-25	F	Speed of stern seal fans, rpm
	26-35	F	Number of data points (maximum of 25)
	36-45	F	As option 1 above
2,3..	1-80	8F10	Tabular values of fan pressure differential, psf
After last pressure data card	1-80	8F10	Corresponding volumetric flow rates cu.ft./sec.

Note: The tabular pressure data for all the fans must be stored in order of increasing pressure. (See discussion in Function FG1). The data is for a single fan.

Structure of Input Deck - The input deck for a given case or series of cases may be considered as being divided into two parts, "basic" data and specific data. Basic data is defined as those inputs which are required to adequately represent the craft regardless of the type of case being considered. Data such as mass properties, craft geometry, fan maps, etc. fall into this category. Specific data is defined as those inputs which are needed to define a specific problem such as runs in waves vs. calm water, rudder motion vs. no rudder motion, etc.

The input cards which constitute the basic data are summarized below by control and option tag along with a

brief description of the input. An asterisk indicates that more than one input card is read in under the given control and option tag.

Required Input Summary (Listed in Numerical Order)

Control Tag and Option	Description
00101	Timing information
00103	Number of integrators and error tolerances
00201 or 00202*	Mass and inertias or mass dstribution
00300	Craft geometric data
00401	Sidewall basic data
00500	Stern seal basic data
00600	Bow seal basic data
00701	Plenum geometry
00702	Froude number at hump speed
00801	Propulsion system basic data
00901	Rudder geometry
01000	Aerodynamic reference lengths
01200	Initial conditions
01300	End of data for one case
01400	End of all cases
01600	Thrust map input
01700	Rudder motions input
01901*	Bow seal fan maps
01902*	Cushion fan maps
01903*	Stern seal fan maps

*More than one input card under this control tag and option.

Optional Input Summary (Listed in Numerical Order)

Control Tag and Option	Description	Program Action if Input Card Is Not Used
00102*	Subroutine print switches	No printout from individual subroutine
00104*	Tabular summary print switches	No tabular summary
00105	Option swithces for lateral plane motions only, trim calculations and constant speed runs	Six Degrees of freedom, fixed thrust (unless engine out is requested, surge velocity allowed to vary
01101*	Wave input	Calm water
01800	Title card	No title printed

Multiple Case Runs - In running multiple cases it is important that the user remember that any input data that is not read in again will be repeated from the previous case. Consider the case where a run is to be made consisting of a run in waves followed by a turn in calm water at a different speed. Assume both intermediate and tabular ouput is desired for both cases. In terms of control tags the deck might look as follows:

00101	Required Input
00103*	
00202*	
00401	
00500	
00600	

*More than one input card under this control tag and option.

00701	
00801	
00901	
01000	
01200	
01600*	
01700	
01901*	
01902*	
01903*	
00102*	Intermediate print
00104*	Tabular print
01102*	Wave input
01300	End of case 1
01200	New initial conditions
01603	Rudder motion
01102*	Wave input
01300	End of case 2
01400	End of run

The purpose of the wave input card in case 2 is to read in the number of waves as zero (calm water). Without this card case 2 would become a turn in waves. Similarly, if a run were to be made with case 1 being an engine out run and case 2 being a turn with both engines operating, case 2 would have to reset the engine out time to a time larger than the run finish time by reading a large time on an 00802 card

*More than one input card under this control tag.

(if case 2 had a finish time less than the engine out time from case 1 it would not be necessary to read this card).

Output - The output from INCON is printed after an end of case card (01300) is read. It is a combination of input data and calculated results. A sample case is given in the input at the end of the report.

(This page intentionally blank)

Subroutine INTGRL

Discussion - Subroutine INTGRL is used to integrate a system of ifrst order ordinary differential equations. It uses a variable time step technique based on the Runge-Kutta-Merson algorithm. A fixed time step R-K also available - See Block 1 option tag 3 for a discussion on its use. The program will stop the calculation if the time step becomes smaller than 10^{-6} sec.

Usage - CALL INTGRL (TIME)

Descriptions of Parameters

TIME = current value of the independent variable

Input - The input to subroutine INTGRL is controlled by the 00103 control tag as discussed in block 1 of subroutine INCON.

Output - If the integration step size is halved, INTGRL will print the current value of time, the new value of the time step, the integrator number, the calculated error and the input maximum error as shown in the sample output at the end of the report. This output is useful as it tells the user which integrator is causing the step size to be reduced and may indicate an excessively tight input error tolerance (see discussion of 00103 card in discussion of subroutine INCON).

Subroutine PROP

Discussion - Subroutine PROP is used to calculate forces and moments on the craft due to the propulsion system. The subroutine has the capability of uneven thrusting and receives this information by using the Function Program FG1 to linearly interpolate a map input in block 16.

Usage - CALL PROP

Input - The input to subroutine PROP is controlled by block 8 and block 16 of subroutine INCON and is discussed there.

Output - The output from PROP is controlled by print option switch IPROP. If this switch is 1, the program will print the calculated forces and moments as shown in the sample output at the end of the report.

Subroutine RHS

Discussion - Subroutine RHS is the subprogram containing the FORTRAN expressions for the right hand side of the system of first order differential equations. It contains the logic to calculate the bubble volume, area and pressure as a function of time as well as the logic which sums the individual forces, moments and leakages from the various craft components to get craft totals. RHS also contains the statements used for the writing of the scratch file for the tabular output.

Usage - CALL RHS (VALUE)

Description of Parameters

VALUE = The array containing the values of the right hand side of the differential equations as calculated in RHS, i.e., for a system of equations of this form $y_i = f_i(y_i, t)$ the VALUE array is used to store the values of $f_i(y_i, t)$

Input - None

Output - The output from RHS is controlled by print option switch IHRS. When this switch is 1, the subroutine will print the output shown in the sample output in the back of the report.

Subroutine RUDDER

Discussion - Subroutine RUDDER contains the logic for calculating rudder forces and moments as well as rudder motions. Rudder motions are calculated by employing the Function Program FG1 to linearly interpolate a map input in block 16 of INCON.

Usage - CALL RUDDER

Input - The input to RUDDER is controlled by block 9 and 16 in Subroutine INCON and is discussed there.

Output - The output from rudder is controlled by print option switch IRUD. If this switch is 1, the program will print out the total forces and moments due to the rudder as shown in the sample output in the back of the report.

Subroutine SIDEWL

Discussion - Subroutine SIDEWL calcualtes the forces and moments acting on the craft due to the sidewalls as well as the leakage flow rates associated with any gaps which open under the sidewalls due either to craft motion or waves.

Usage - CALL SIDEWL

Input - The input to subroutine SIDEWL is controlled by blocks 3 and 4 of subroutine INCON and is discussed there.

Output - The output from SIDEWL is controlled by the print option switch ISIDWL. When this switch is equal to 1, the program will print the sidewall gaps, immersion depths and total forces and moments due to the sidewall-appendage combination as shown in the output listing at the back of the report.

Subroutine STNSL

Discussion - Subroutine STNSL calculates the forces and moments acting on the craft due to the stern seal as well as the leakage flow rates arising from any gaps which open under the seal. The craft equilibrium leakage area is assumed to be located in the stern seal.

Usage - CALL STNSL

Input - The input data for STNSL is controlled by blocks 3, 5, and 17 of subroutine INCON and is discussed there.

Output - The output from STNSL is controlled by print option switch ISTNSL. When this switch is equal to 1, the program will print the seal wetted lengths, and gaps as a function of station as well as the craft forces and moments due to the stern seal. An example is contained in the sample output at the back of the report.

Functions T1 and T2

Discussion - Functions T1 and T2 are two small Function subprograms used to calculate various trignometric relations used by subroutine WAVES.

Subroutine WAVES

Discussion - Subroutine WAVES calculates the wave forces and moments acting on the craft. It also generates the wave heights at the various stations around the seals and sidewalls, as well as the bubble volume lost due to wave elevation.

The sea state for irregular seas is computed in WAVES by adding together a series of regular waves with an appropriate distribution of amplitude and frequency.

Usage - CALL WAVES

Input - The input to subroutine WAVES is controlled by block 11 of subroutine INCON and is discussed there.

Output - The output from WAVES is controlled by print option switch IWAVES. When this switch is set equal to 1, WAVES will print the wave elevation around the seals and sidewalls, the wave elevation at the center of gravity and the volume reduction of the bubble plenum due to waves as well as the total forces and moments acting on the craft due to waves.

USERS MANUAL FOR THE PLOTTING

PACKAGE

(INCLUDES THE MULTICURVE OPTION)

DESCRIPTION:

The plotting package of the COLFIL subroutine is a flexible routine that allows the user to:

1) Plot on either the CALCOMP or the printer
2) Plot up to 3 curves per graph on the CALCOMP
3) Intermix multicurve CALCOMP and single curve CALCOMP plots
4) Revise the variables plotted on successive runs
5) Choose from up to 26 different variables
6) Print up to 16 variables per run
7) Revise the variables printed on successive runs

The method of employing this routine must be adhered to or errors will result. JCL for calling this routine is found at the end of this manual.

MEANING OF THE CARD

1. Block 20

Card	Columns	Format	Entry
1	1-3	I3	020
2	This card must be used if card 1 appears. See sample input		
	1-10	I1	NCURV is the number of this curve on the corresponding graph, ie; Col. 1 pertains to graph 1, Col. 2 - graph 2, etc.

Card	Columns	Format	Entry
			A "0" must appear in these columns if only one curve per graph is to be plotted. "1" must appear if this is the first of more than one curve per graph, a "2" if this is the intermediate curve and a "3" if this is the last curve on this graph.

2. Block 21

Card	Columns	Format	Entry
1	1-3	I3	021 - Causes the summary variables to be read
2	1-16	8I2	Punch in the numbers corresponding to the variable names desired to be printed in summary one.
3	1-16	8I2	The same as card one but, for Summary Two, these cards need not be repeated for successive runs unless changes are desired.

3. Block 22

Card	Columns	Format	Entry
1	1-3	I3	022 - Read in the number of graphs desired, whether or not Calcomp is desired. Read the X and Y axes for the graphs and read the first line

Card	Columns	Format	Entry
			of the graph title.
2	1-2	I2	The number of graphs desired right justified, up to and including 10.
	3-4	I2	A zero if print plot is desired or a 1, right justified, if CALCOMP is desired.
3	1-50	25I2	The numerical values of the X and Y axes alternating in the following manner. The X axis of the first graph then the Y axis of the first graph and continuing for all desired graphs. A table relating axis number and name is at the end of this paper.
4	1-48	6A8	The Alpha-numeric title that will appear on the first line of the CALCOMP plot. If CALCOMP is not desired, replace this card with a blank card. Your name should appear somewhere on this line for computer identification purposes.

SAMPLE INPUT DECK

020

11 — This indicates that this is the first of multiple curves on graphs 1 and 2.

021

0115 — Summary one will print the first two variables,
0116 — 01, 15, and summary two the following two, 01, 16.

022

0201 — Two graphs are called for, and a CALCOMP output

01150116 — Graph 1 plots 01, 15, Time and X displacement

Graph 2 plots 01, 16, Time and Y displacement

SES output for LEO

Standard input deck

013

020
22
021 — As Above. These can be changed on subsequent runs.
1516
0115

Changes desired

013
020
33
021 — As Above.
1325
0116

Changes desired

013
014

RELATION OF VARIABLE NAME AND NUMBER

NUMBER	NAME
01	Time
02	Wave Height
03	Z Displacement
04	Pitch Angle
05	Plenum Pressure
06	Bow Acceleration
07	C. G. Acceleration
08	Fan Power
09	Roll Angle
10	Yaw Angle
11	Lateral Acceleration
12	Speed through the water
13	Turn Radius
14	Turn Rate
15	X Displacement
16	Y Displacement
17	Air Flow in
18	Air Flow out
19	Net Force X Direction
20	Wave Force X Direction
21	Net Force Y Direction
22	Net Force Z Direction

NUMBER	NAME
23	Net Torque X Axis
24	Net Torque Y Axis
25	Net Torque Z Axis
26	Rudder Angle

APPENDIX A-A

CHANGING THE MODEL

Changing the Model

Appendix A-A

Introduction

As previously stated, the program has been written in a modular form to facilitate changes to the program which reflect major design changes to the craft, i.e., a different type of seal, addition of controls, etc. Since it is obviously impossible to program all possible configurations in one program, these types of changes will require either replacing a whole module (sub-program) or altering the Fortran statements within a given sub-program. In order to achieve this, a more detailed knowledge of the structure of the program and the method of data transference between subprograms is required. This appendix will attempt to give a brief explanation of the program structure and will then discuss the details of how one would make certain anticipated changes.

General Structure

The primary variables (displacements, velocitites, pressure, etc.) are contained in an array of length 40 words, named VAL; which is transmitted through the various subprograms using a labelled common block called VARBLE. Within each subprogram the various elements of VAL are equivalenced to local variables, which are given mnemonic names which closely resemble the standard mathematical symbols used for the variable (e.g. u, v, w, p_B become U,V, W, PB in the

Fortran listing). The second through the sixteenth elements of VAL are reserved for the output of integrators and must be used in numerical order, i.e., when adding a new equation to be integrated, the output of the integrator must be equivalenced to the first unused location in VAL (VAL(12) for the current program).

The force and moment components acting on the craft are calculated for each element in the appropriate subprogram and are transmitted through various labelled common blocks. These force and moment components are then summed in subroutine RHS to get the appropriate acceleration and velocity components. The accelerations and velocities are transmitted back to subroutine INTGRL in an array called VALUE. INTGRL then integrates these first derivatives to get the new velocities and displacements.

Anticipated Changes

a. Replacing Analytic Coefficients or Curve Fits With Tabular Experimental Data

As experimental data is obtained it may be desired to replace coefficients based on analytic calculations or estimations from simple shapes by the experimental data. This data will often be tabular in nature. For functions of a single variable this is quite simple to do as the necessary table look-up routine already exists within the program (function FG1). The user would be required to make the following changes.

1. Statements to read in the tabular data must be added to subroutine INCON.
2. A common block must be provided to transfer the data to the subroutine where it is to be used.
3. A statement must be added to call FG1 to do the table look-up.

A good example of the above procedure is afforded the user by the fan maps as currently programmed. This logic uses tabular data and the user should refer to input block 19 of subroutine INCON and subroutine FAN to see an example of the three steps outlined above.

b. Adding a Stern Seal Equation of Motion

The current program has a stern seal model which is based on the assumption that the seal is completely deformable (no stiffness) and as such there is no dynamic equation of motion. For seal designs where there is an appreciable degree of stiffness a seal equation of motion should be added.

Assume that the seal equation of motion to be added is a standard spring-mass-damper system and therefore may be represented by the following system of first order differential equations.

$$\dot{\alpha}_s = (-d\theta_s - k\theta_s + M_s)/m \qquad (1)$$

$$\dot{\theta}_s = \alpha_s \qquad (2)$$

The following program changes would have to be made in order to incorporate Equations (1) - (2) into the current program.

1. Logic must be added to block 5 of subroutine INCON to read in and store the constants d, k, and m as well as the initial conditions for θ_s and $\dot{\theta}_s$. Care should be taken in the case of the latter to save these initial conditions using Fortran variables with names other than the names which will contain the current (running) values of the seal displacement and velocity. This is due to the fact that when running multiple cases the program will use the currently stored values of θ_s and $\dot{\theta}_s$ from the old case as initial conditions for the new case unless the initial conditions are reset. An example of this can be seen on page 205 of the program listing after statement number 1200 where the craft initial conditions are read in. Saving the initial conditions under a different name also has the advantage of allowing the input to be in degrees rather than in radians as required by the program, as the conversion can be done in the arithmetic replacement statements added in step 2 below.

2. In block 13 of INCON, (after statement 1300 but before statement 1400) arithmetic replacement statements should be added to convert the initial conditions to radians and radians/sec. and then store these values in the running variables for θ_s and $\dot{\theta}_s$ (see page 205 of the program listing after statement 1302 for an example). Note that in the program the variable RAD is the number of degrees in a radian and may be used for the conversion of units (see example cited above.)

3. The variable names for the seal velocity and displacement should be equivalenced to VAL (12) and VAL (13) respectively. This automatically makes these variables the output of integrators. This equivalence statement should appear in subroutines INCON, RHS and STNSL.

4. The number of differential equations on the input card after the 00103 card should be increased from 10 to 12, indicating that two additional differential equations have been added. In addition, error tolerances for these integrators must be given (see page 154 of this report for a discussion of this point.)

5. A common block to transmit d, k, and m must be added to subroutines INCON and RHS.

6. In subroutine RHS the Fortran equivalent of the right hand side of Equation (1) must be set equal to VALUE (11) while $\dot{\theta}_s$ must be set equal to VALUE (12). (See examples in listing of subroutine RHS.)

7. In subroutine STNSL the expressions for M_s, the total applied moment on the stern seal about its hinge point must be added. These are placed in STNSL as this subroutine has the logic for calculating wave elevations relative to the seal, etc. In addition, the equations for the stern seal leakage gap is STNSL must be modified to take into account the seal motion.

8. A common block must be added to subroutines STNSL and RHS to transmit the value of the moment M_s to RHS.

c. Adding New Forces or Moments Acting on a Craft

If the modification of the program entails the addition of any new force or moment component acting on the craft, care must be taken to add this component to the bending moment calculations as well as the craft motion calculations. If this is not done the equilibrium check done by subroutine SAM prior to calculating the bending moments will not balance and the calculation will be terminated.

The following changes would have to be made:

1. In subroutine RHS the new force component should be added to the WRITE statement preceding statement number 111 on page 218 of the program listing as well as into the calculation of GF in RHS. If the force component has a fixed moment arm, a common block should be added to transmit its value to subroutine SAM. If the moment arm is time varying the moment arm should also be added to the WRITE statement.

2. In subroutine SAM the force and arm (if necessary) should be added to the following READ or WRITE statements; page 220 , statement numbers 42 and 44; page 220 , after statement number 6.

   The force and moment components must be added to the equilibrium check on the top of page .

   The force and moment components must be added to the calculation of the longitudinal and lateral moment and shear calculations. In these calculations the variables XMI(IX) and YMI(IY) are the distance to the current plane of interest. The user should study the current program listing (pages 183 - 233) to ascertain the procedure used to add these force and moment components.

APPENDIX A-B

ABNORMAL TERMINATION MESSAGES

ABNORMAL TERMINATION MESSAGE	SUBPROGRAM	PROGRAM ACTION	USER ACTION
CRAFT SPEED BELOW HUMP SPEED	MAIN	Go to next case	None
INPUT ERROR -- STOP -- ISYS = XXX	INCON	Stop run	Check input data for mispunched card or card out of place. Program has read a card with an invalid program control tag (ISYS).
ERROR IN INPUT --- DELT AND/OR DELPNT EQUALS ZERO --- JOB ABORTED	INCON	Stop Run	Check 00101 input card and fix error. Program would loop indefinitely if allowed to continue.
ERROR IN INPUT --- INPUT INERTIA	INCON	Stop Run	Inertia matrix is singular. Check 00201 card or mass distribution to find error.
DELTA TIME LESS THAN 1.0E-6 -- JOB STOPS	INTGRL	Stop Run	The time step has been halved to below 10^{-6} sec. Check any intermediate output for unusual values. Check the derivative (K1) and the state variables (VAL) printed with this error message for any unusual numbers.

APPENDIX A-C

SIDEWALL INTEGRAL TABLE PROGRAM

DISCUSSION

Sidewall Integral Table Program

Appendix A-C

The sidewall Integral Table Program evaluates tables of integrals of sectional hydrostatic and hydrodynamic properties over the whole and partial lengths of a SES sidewall. These tables are calculated as a function of sidewall draft, trim and length of a regular wave. The tables are then subsequently accessed by the main SES Motions and Load Program and when combined with knowledge of both the craft and waves instantaneous position and motion produces the hydrostatic and hydrodynamic forces and moments acting on the sidewalls.

The primary input to this program is a table of waterlines and corresponding beams for each chosen station with arbitrary spacing in both waterlines and stations. The program is thus applicable to a general sidewall form. In addition to this input, the user must specify the range of drafts, trim (pitch) angles, and wavelengths (encompassing all components of a specified sea state) that the craft is expected to range thru in the subsequent simulations performed by SES Motions and Loads Program. The wave-lengths are specified via the wavelengths parameter $(2\pi/\lambda)$. The first value of this parameter must be zero which corresponds to an infinite wavelength and is used to SIDEWL subroutine of the SES Motions and Loads Program to determine hydrostatic and hydrodynamic forces due to body motion alone.

The tables at the remaining values are used by the WAVES subroutine for wave induced forces. Since the center of gravity is not necessarily known at the time this program is executed, the user must also specify a longitudinal reference coordinate measured from the transom about which the integrals are to be evaluated (a value near mid-ships is recommended). The range of drafts and trims at the longitudinal reference point must be selected in such a manner so that the top of the plenum does not sink below the water surface.

The description and order of the cards of the input data deck is as follows:

1st Card

Columns	Format	Entry
1-5	I	No. of wave parameters ≤ 20
6-10	F	increment in wave parameters (ft.$^{-1}$)
11-15	F	first value of wave parameter (ft.$^{-1}$)
16-20	I	no. of drafts ≤ 5
21-25	F	increment in draft (in.)
26-30	F	first value of draft (in.)
31-35	I	no. of trims ≤ 7
36-40	F	increment in trim (deg.)
41-45	F	first value of trim (deg.)
46-50	I	no. of stern beams ≤ 36
51-55	F	increment of stern beam (ft.)
56-60	F	first value of stern beam (ft.)

2nd Card

Columns	Format	Entry
1-5	I	no. of stations = NSTA ≤ 95
6-10	I	max. no. of drafts per station ≤ 8

3rd Card

Columns	Format	Entry
1-5	F	distance from keel to top of plenum (ft.)

4th Card

Columns	Format	Entry
1-10	F	distance of reference position from transom (ft.)

5th Card

Columns	Format	Entry
1-5	I	no. of integral limits in addition to the integral over the whole length ≤ 10
6-75	10F5	integral limits (distance from transom) (ft.)

Next NSTA Cards (one card per station)

Columns	Format	Entry
1-5	F5	distance of station from bow (in.)
6-10	F5	lowest waterline beam (ft.)
11-15	F5	corresponding height of beam (ft.)
16-20	F5	next waterline beam (ft.)
21-25	F5	corresponding height of beam (ft.)

Columns	Format	Entry
.	.	
.	.	
.	.	
66-70	F5	next waterline beam (ft.)
71-75	F5	corresponding height of beam (ft.)

This program transmits the calculated tables to the SES Motions and Loads Program by writing the tables on units which are later read by the main program. Unit number 10 contains the tables obtained by integrating over the entire length and the succeeding units contain the tables obtained by integrating over partial lengths.

APPENDIX B

FORTRAN PROGRAM LISTING

```
C
C
C     MAIN AND BLOCK DATA
      INTEGER ON

      COMMON /AIR/ PINF,RHOINF,GAM
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IY
      COMMON /CONST/ PI,RAD,UO
      COMMON/ENGINE/NPS,NPP,THSTS(25),THSTP(25),XP,YP,ZP,STHS,STHP,
     ATIP(25),TIS(25)
      COMMON /EQNCO/ NEQS,TCL(20),JQQ
      COMMON /FPROP/ FXP,FYP,FZP,FKP,FMP,FNP
      COMMON / FROUDE / FN,FNCRIT
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,
     -IRUD,IPROP,IAEROD,IRHS
      COMMON /ROLL/ PHIMAX,TROLL
      COMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRCS,TL,RSPAN,RAREA,RASPR,
     ARCLB,RTC,RUDANG,TIR(25)
      COMMON / VALOLD / YOLD(20)
      COMMON /VARBLE/ VAL(40)
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVCLW,NWAVE,BETA,
     1               FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV
     2               ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR

      EQUIVALENCE            (VAL(2),U),(VAL(3),V),(VAL(4),W),
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),
     3(VAL(24),PB)
      DIMENSION DUMMY(20)

      TC=1.0
      ON=1
      PI=4.*ATAN(1.)
      RAD=180./PI
      WRITE(6,100)
100   FORMAT(1H1//35X,22H LISTING OF INPUT DECK  //)
99    READ(44,101,END=104) DUMMY
101   FORMAT(20A4)
105   WRITE(6,102)DUMMY
      WRITE(5,101) DUMMY
102   FORMAT(5X,20A4)
      GO TO 99
104   REWIND 5

11    CALL INCON(TIME)
      IF (IMM.EQ.3)  GO TO 605
```

```
      DO 10 J=1,20
10    YOLD(J)=VAL(J+1)
      GO TO 2

 1    CONTINUE
      TOLD=TIME
      PBBAR=PBBAR*(1.-DELT/TC)+DELT*(PB-PINF)/TC
      IF ( NWAVE.LE.0 )  GO TO 13
      ZBAR=(1.-DELT/TC)*ZBAR+DELT*Z/TC
      PHIBAR=(1.-DELT/TC)*PHIBAR+DELT*PHI/TC
      THEBAR=(1.-DELT/TC)*THEBAR+DELT*THETA/TC
      CALL WAVES(TIME)

 13   CALL SIDEWL
      CALL PROP
      CALL RUDDER
      CALL AEROD
      CALL INTGRL(TIME)
      IF(TIME.GT.FTIME) GO TO 12
      IF ( FN.GT.FNCRIT) GO TO 14
      PRINT 505
      GO TO 12

 14   DELOLD=TIME-TOLD
      PSI=PSI+DELOLD*R
      X=X+DELOLD*(U*COS(PSI)-V*SIN(PSI))
      Y=Y+DELOLD*(U*SIN(PSI)+V*COS(PSI))
15    IF (ABS(TIME-TPRINT) .LT. 1.E-6) GO TO 2
      GO TO 1

 2    CONTINUE
      IF(ITRAJ .EQ. 0) GOTO 16
      DPHI=PHI*RAD
      DPSI=PSI*RAD
      DTHETA=THETA*RAD
      DP=P*RAD
      DQ=Q*RAD
      DR=R*RAD
      VEL=0.5925*U
      WRITE (6,500) TIME,VEL,V,W,DP,DQ,DR,Z,DPHI,DTHETA,X,Y,DPSI
      BETS=(-V/U)*RAD
      DELRS=RUDANG*RAD
      WRITE(6,501) BETS,DELRS,FXP
16    CONTINUE
      IMMTAG = (IMM+1)/2
      IF ( IMMTAG .EQ. 1  .AND. TIME.GE.BTIME-1.E-8 )  IMT = 1
      TPRINT=TPRINT+DELPNT
      ON=1
```

```
      GO TO 1
12    CALL COLFIL
      IF (IMM.LT.1)  GO TO 11
      IF (IMM.NE.1)  GO TO 605
      END FILE IBMFIL
      GO TO 11
605   CALL SAM
      GO TO 11
500   FORMAT(//10X,13HTIME (SEC) =  F6.2//10X,33HTRANSLATIONAL VELS (KTS
     1)/(FT/SEC) /10X,2HU= F6.2,5X,2HV= F6.2,5X,2HW= F6.3//10X,31HROTATI
     2ONAL VELOCITIES (DEG/SEC) /10X,2HP= F6.2,5X,2HQ= F6.2,5X,2HR= F6.2
     3//10X,30HDISPLACEMENTS (FT AND DEGREES) /10X,2HZ= F7.3,5X,4HPHI=
     4F6.2,3X,6HTHETA= F6.2//10X,27HTRAJECTORY (FT AND DEGREES) /10X,
     52HX= F8.2,4X,2HY= F8.2,4X,4HPSI= F8.2)
501   FORMAT(1H0,9X,23HSIDESLIP ANGLE (DEG) =    F8.2,10X,21HRUDDER ANGLE
     1 (DEG) =  F8.3,10X,15HTHRUST (LBS) =   F12.1)
505   FORMAT(///25X,28HCRAFT SPEED BELOW HUMP SPEED )
      END
      BLOCK DATA
      COMMON /AIR/ Z1(3)
      COMMON /BMCO/ Z2(25)
      COMMON /COLUMN / Z3(2)
      COMMON /CONST/ Z4(3)
      COMMON /CNTRL/ Z5(10)
      COMMON /ENGINE/ Z6(107)
      COMMON /EQNCO/ Z7(22)
      COMMON /FAERO/ Z8(6)
      COMMON /FAIR/ Z9(2)
      COMMON /FANMAP/ Z10(262)
      COMMON /FORRS/ Z11(7)
      COMMON /FORSS/Z12(8)
      COMMON /FPROP/ Z13(6)
      COMMON /FROUDE/ Z14(2)
      COMMON /FRUD/ Z15(6)
      COMMON /GBOW/ Z16(1)
      COMMON /GEOM/ Z17(138)
      COMMON /GEOMBS/ Z18(62)
      COMMON /GEOMSS/ Z19(62)
      COMMON /GEOMSW/ Z20(11)
      COMMON /KSWTCH/ Z21(1)
      COMMON /LEAKER/ Z22(4)
      COMMON /MASSES/ Z23(317)
      COMMON /MATRIX/ Z24(36)
      COMMON /MSIDW/ Z25(55)
      COMMON /MWAVE/ Z26(12)
      COMMON /OPTION/ Z27(3)
      COMMON /PLENUM/ Z28(4)
```

```
      COMMON /PLVCQQ/ Z28A(4)                                          MN  1440
      COMMON /PRIME/ Z29(5)                                            MN  1450
      COMMON /PRTINT/ Z30(12)                                          MN  1460
      COMMON /PWAVE/ Z31(2)                                            MN  1470
      COMMON /RISER/ Z32(1)                                            MN  1480
      COMMON /ROLL/ Z33(2)                                             MN  1490
      COMMON /RUDDR/ Z34(62)                                           MN  1500
      COMMON /SIDE/ Z35(22)                                            MN  1510
      COMMON /SOFTBS/ Z36(19)                                          MN  1520
      COMMON /SOFTSS/ Z37(19)                                          MN  1530
      COMMON /STABLE/ Z38(5)                                           MN  1540
      COMMON /STSLR/ Z39(2)                                            MN  1550
      COMMON /VALOLD/ Z40(20)                                          MN  1560
      COMMON /VARBLE/ Z41(40)                                          MN  1570
      COMMON /WAVE/ Z42(80)                                            MN  1580
      COMMON /WAVEF / Z43(40)                                          MN  1590
      DATA Z1/3*0.0/                                                   MN  1600
      DATA Z2/25*0.0/                                                  MN  1610
      DATA Z3/2*0.0/                                                   MN  1620
      DATA Z4/3*0.0/                                                   MN  1630
      DATA Z5/10*0.0/                                                  MN  1640
      DATA Z6/107*0.0/                                                 MN  1650
      DATA Z7/21*0.0/                                                  MN  1660
      DATA Z8/6*0.0/                                                   MN  1670
      DATA Z9/2*0.0/                                                   MN  1680
      DATA Z10/262*0.0/                                                MN  1690
      DATA Z11/7*0.0/                                                  MN  1700
      DATA Z12/8*0.0/                                                  MN  1710
      DATA Z13/6*0.0/                                                  MN  1720
      DATA Z14/2*0.0/                                                  MN  1730
      DATA Z15/6*0.0/                                                  MN  1740
      DATA Z16/0.0/                                                    MN  1750
      DATA Z17/138*0.0/                                                MN  1760
      DATA Z18/62*0.0/                                                 MN  1770
      DATA Z19/62*0.0/                                                 MN  1780
      DATA Z20/11*0.0/                                                 MN  1790
      DATA Z21/0.0/                                                    MN  1800
      DATA Z22/4*0.0/                                                  MN  1810
      DATA Z23/817*0.0/                                                MN  1820
      DATA Z24/36*0.0/                                                 MN  1830
      DATA Z25/55*0.0/                                                 MN  1840
      DATA Z26/12*0.0/                                                 MN  1850
      DATA Z27/3*0.0/                                                  MN  1860
      DATA Z28/4*0.0/                                                  MN  1870
      DATA Z28A/4*0.0/                                                 MN  1880
      DATA Z29/5*0.0/                                                  MN  1890
      DATA Z30/12*0.0/                                                 MN  1900
      DATA Z31/2*0.0/                                                  MN  1910
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      DATA Z32/0.0/                                                     MN  1920
      DATA Z33/2*0.0/                                                   MN  1930
      DATA Z34/62*0.0/                                                  MN  1940
      DATA Z35/22*0.0/                                                  MN  1950
      DATA Z36/19*0.0/                                                  MN  1960
      DATA Z37/19*0.0/                                                  MN  1970
      DATA Z38/5*0.C/                                                   MN  1980
      DATA Z39/2*0.0/                                                   MN  1990
      DATA Z40/20*0.0/                                                  MN  2000
      DATA Z41/40*0.0/                                                  MN  2010
      DATA Z42/80*0.0/                                                  MN  2020
      DATA Z43/40*0.0/                                                  MN  2030
      END                                                               MN  2040
C                                                                       AER 0010
C                                                                       AER 0020
      SUBROUTINE AEROD                                                  AER 0020
      INTEGER ON                                                        AER 0030
      COMMON /FAERO/ FX,FY,FZ,FK,FM,FN                                  AER 0040
      COMMON /FAIR/ RHOA,XLAERO                                         AER 0050
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,  AER 0060
     -IRUD,IPROP,IAEROD,IRHS                                            AER 0070
      COMMON /VARBLE/ VAL(40)                                           AER 0080
                                                                        AER 0090
      EQUIVALENCE             (VAL(2),U),(VAL(3),V),(VAL(4),W),         AER 0100
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),     AER 0110
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),AER 0120
     3(VAL(24),PB)                                                      AER 0130
      QA=RHOA*U*U                                                       AER 0140
      QAL=QA*XLAERO                                                     AER 0150
      BETA=-V/U                                                         AER 0160
      BETASQ=BETA*BETA                                                  AER 0170
      FX=-(0.90*BETASQ+0.13)*QA                                         AER 0180
      FY=(0.0*BETASQ+0.53*BETA)*QA                                      AER 0190
      FZ=-(2.06*BETASQ+0.39)*QA                                         AER 0200
      FK=-(0.5 BETASQ+0.0*BETA)*QAL                                     AER 0210
      FM=(0.29*BETASQ+0.12)*QAL                                         AER 0220
      FN=(0.0*BETASQ+0.076*BETA)*QAL                                    AER 0230
                                                                        AER 0240
      IF (IAEROD.NE.ON) RETURN                                          AER 0250
                        WRITE(6,100) FX,FY,FZ,FK,FM,FN                  AER 0260
  100 FORMAT(/10X,23HAEROD FX,FY,FZ,FK,FM,FN/6E15.4)                    AER 0270
      RETURN                                                            AER 0280
      END                                                               AER 0290
C                                                                       BSL 0010
C                                                                       BSL 0010
      SUBROUTINE BOWSL                                                  BSL 0020
      INTEGER ON                                                        BSL 0030
      COMMON /AIR/ PINF,RHOINF,GAM                                      BSL 0040
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      COMMON /CONST/ PI,RAD,UO                                          BSL 0050
      COMMON / FORBS/ FX,FY,FZ,FK,FM,FN,QL                              BSL 0060
      COMMON /GEOM/     WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM    BSL 0070
     1,DELS(4,10),XCP,ZCP                                               BSL 0080
      COMMON /GEOMBS/DETABX(11),DETABT(11),ARM1B(10),ARM2B(10)          BSL 0090
     1 ,DFBS(10),TSKIB(10)                                              BSL 0100
      COMMON/LEAKER/ALEAK,BLEAK,CFSS,CFBS                               BSL 0110
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,  BSL 0120
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO       BSL 0130
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBCWSL,ISTNSL,IWAVES,  BSL 0140
     -IRUD,IPROP,IAEROD,IRHS                                            BSL 0150
      COMMON/SOFTBS/XBF,PBS,SINBS,COSBS,XBS,ZBS,DELYBS,DPBS,ELMAXB,YAVG BSL 0160
     1B(10)                                                             BSL 0170
      COMMON /VARBLE/ VAL(40)                                           BSL 0180
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),CVCLW,NWAVE,BETA,        BSL 0190
     1                 FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV              BSL 0200
     2                 ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR       BSL 0210
      DIMENSION GAP(11),ELSKI(11)                                       BSL 0220
      DIMENSION WTAB(6),ZTAB(6)                                         BSL 0230
      DATA NPTS,IBS/6,0/                                                BSL 0240
      DATA WTAB/0.0,3.75,5.42,6.67,7.5,8.42/                            BSL 0250
      DATA ZTAB/3.75,4.00,4.42,4.83,5.25,5.67/                          BSL 0260
      DATA ENU,UWSKI,CLSKI/1.28E-05,0.0,1.5708/                         BSL 0270
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),       BSL 0280
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),     BSL 0290
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),BSL 0300
     3(VAL(24),PB)                                                      BSL 0310
      DO 5 J=1,11                                                       BSL 0320
      GAP(J)=0.0                                                        BSL 0330
      ELSKI(J)=0.0                                                      BSL 0340
    5 CONTINUE                                                          BSL 0350
      ALBS=0.0                                                          BSL 0360
      FX=0.0                                                            BSL 0370
      FZ=0.0                                                            BSL 0380
      FK=0.0                                                            BSL 0390
      FM=0.0                                                            BSL 0400
      FN=0.0                                                            BSL 0410
      DELPBG=PBS-PB                                                     BSL 0420
      IF(DELPBG.LT.0.0) DELPBG=0.0                                      BSL 0430
      PBAR=PB-PINF                                                      BSL 0440
      DELP=PBAR                                                         BSL 0450
      IF(DELP.LT.0.0)DELP=0.0                                           BSL 0460
      SINDIF=SINBS-COSBS*THETA                                          BSL 0470
      COSDIF=COSBS+SINBS*THETA                                          BSL 0480
      X1=XBS+ZBS*THETA-XBF*SINDIF                                       BSL 0490
      Z1=-Z-ZBS+XBS*THETA-XBF*COSDIF                                    BSL 0500
      N=NSTA(3)                                                         BSL 0510
      DO 10 K=1,N                                                       BSL 0520
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      ELSKI(K)=(ETA(3,K)-DETABX(K))*(XX(3,K)-X1)-Z1+YY(3,K)*PHI          BSL 0530
      GAP(K)=-ELSKI(K)                                                  BSL 0540
      IF(GAP(K).LT.0.0) GAP(K)=0.0                                      BSL 0550
   10 CONTINUE                                                          BSL 0560
      N=NSTA(3)-1                                                       BSL 0570
      DO 20 J=1,N                                                       BSL 0580
      ELSKIA=(ELSKI(J+1)+ELSKI(J))/2.0                                  BSL 0590
      IF(ELSKIA.LE.0.0) GO TO 15                                        BSL 0600
      IF(ELSKIA.GT.ELMAXB) ELSKIA=ELMAXB                                BSL 0610
      ARM1B(J)=XX(3,J)+ELSKIA/2.0                                       BSL 0620
      ARM2B(J)=ZS-ELSKIA                                                BSL 0630
      DFBS(J)=-DELP*ELSKIA*DELYBS                                       BSL 0640
      ARG=0.5*RHO*U*U*ELSKIA*DELYBS                                     BSL 0650
      RESKI=U*ELSKIA/ENU                                                BSL 0660
      CDTSKI=0.427/(ALOG10(RESKI)-0.407)**2.64                          BSL 0670
      TSKIB(J)=-ARG*CDTSKI                                              BSL 0680
      GO TO 18                                                          BSL 0690
   15 DFBS(J)=0.0                                                       BSL 0700
      TSKIB(J)=0.0                                                      BSL 0710
   18 CONTINUE                                                          BSL 0720
      FX=FX+TSKIB(J)                                                    BSL 0730
      FZ=FZ+DFBS(J)                                                     BSL 0740
      FK=FK+DFBS(J)*YAVGB(J)                                            BSL 0750
      FM=FM-DFBS(J)*ARM1B(J)+TSKIB(J)*ARM2B(J)                          BSL 0760
      FN=FN-TSKIB(J)*YAVGB(J)                                           BSL 0770
      ALBS=ALBS+(GAP(J)+GAP(J+1))*DELYBS/2.0                            BSL 0780
   20 CONTINUE                                                          BSL 0790
      ALBS=ALBS+BLEAK                                                   BSL 0800
      QL=CFBS*ALBS*SQRT(2.0*ABS(PBAR)/RHOINF)*SIGN(1.0,PBAR)            BSL 0810
      IF(IBOWSL.NE.ON) RETURN                                           BSL 0820
      WRITE (6,100) GAP,ELSKI,FX,FY,FZ,FK,FM,FN                         BSL 0830
  100 FORMAT(//10X,8HBOW SEAL /26H GAP (FT.) (PORT TO STBD.) /11F10.5   BSL 0840
     1/28H ELSKI (FT.) (PORT TO STBD.) /11F10.5 /10X,23HBOWSL FX,FY,FZ,FBSL 0850
     2K,FM,FN /6E15.4)                                                  BSL 0860
      RETURN                                                            BSL 0870
      END                                                               BSL 0880
C
C                                                                       CFL 0010
      SUBROUTINE COLFIL                                                 CFL 0020
C                                                                       CFL 0030
C     QUESTIONS CONCERNING THE USE OF THIS SUBROUTINE SHOULD BE REFERED CFL 0040
C     TO THE USERS' MANUAL CONTAINED IN THIS THESIS.                    CFL 0050
C                                                                       CFL 0060
      COMMON/AXIS/NXYS(26)                                              CFL 0070
      COMMON/COLUMN/IVERT,ILATPL                                        CFL 0080
      COMMON /CURVE/NCURV(10)                                           CFL 0090
      COMMON/EQNCO/ NEQS,TOL(20),JQQ                                    CFL 0100
      COMMON/GRAF/NGRAF,NDRW                                            CFL 0110
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      COMMON /HEADG/TICRD(6)                                            CFL 0120
      COMMON/STEP/ STEP2                                                CFL 0130
      COMMON /SUM/ ISUM1(8),ISUM2(8)                                    CFL 0140
      REAL*8 TICRD                                                      CFL 0150
      REAL LABEL                                                        CFL 0160
      REAL LAB(4)/'    ','   1','   2','   3'/                          CFL 0170
      REAL*8 NAMES(52)/'TIME    ','        ','WAVE HEI','GHT     ','Z DICFL 0180
     1SPLA','CEMENT  ','PITCH AN','GLE     ','PLENUM P','RESSURE ','BOW CFL 0190
     2ACCE','LERATION','C.G.ACCE','LERATION','FAN POWE','R       ','ROLCFL 0200
     3L ANG','LE      ','YAW ANGL','E       ','LAT ACCE','LERATION','SPECFL 0210
     4ED TH','RU WATER','TURN RAD','IUS     ','TURN RAT','E       ','X DCFL 0220
     5ISPLA','CEMENT  ','Y DISPLA','CEMENT  ','AIR FLOW',' IN     ','AIRCFL 0230
     6 FLOW',' OUT    ','NET FORC','E X DIR ','WAVE FOR','CE X DIR','NETCFL 0240
     7 FORC','E Y DIR ','NET FORC','E Z DIR ','NET TORQ','UE XAXIS','NETCFL 0250
     8 TORQ','UE YAXIS','NET TORQ','UE ZAXIS','RUDDER A','NGLE    '/   CFL 0260
      REAL*8 TITLE(12)                                                  CFL 0270
      REAL*8 LINE2(2)/'PLOT IS ',' VERSUS '/                            CFL 0280
      REAL*8 NAMEX(2),NAMEY(2),INAME(16)                                CFL 0290
      EQUIVALENCE (TITLE(1),TICRD(1)),(TITLE(2),TICRD(2)),(TITLE(3),TI  CFL 0300
     1CRD(3)),(TITLE(4),TICRD(4)),(TITLE(5),TICRD(5)),(TITLE(6),TICRD(  CFL 0310
     26))                                                               CFL 0320
      DIMENSION PVQQ(26),XOUT(900),YOUT(900),AFILE(8)                   CFL 0330
      EQUIVALENCE (PVQQ(1),TIME),(PVQQ(2),ETA),(PVQQ(3),Z),(PVQQ(4),THETCFL 0340
     1A),(PVQQ(5),PB),(PVQQ(6),BOWACC),(PVQQ(7),ACC),(PVQQ(8),FANPWR),(PCFL 0350
     2VQQ(9),PHI),(PVQQ(10),BETAS),(PVQQ(11),ACCLAT),(PVQQ(12),U),(PVQQ(CFL 0360
     313),TRADUS),(PVQQ(14),R),(PVQQ(15),X),(PVQQ(16),Y),(PVQQ(17),QIN),CFL 0370
     4(PVQQ(18),QOUT),(PVQQ(19),GFXXX),(PVQQ(20),FXPWAV),(PVQQ(21),GF2),CFL 0380
     5(PVQQ(22),GF3),(PVQQ(23),GF4),(PVQQ(24),GF5),(PVQQ(25),GF6),      CFL 0390
     6(PVQQ(26),DELRS)                                                  CFL 0400
      IF(JQQ.NE.2) GO TO 1                                              CFL 0410
      WRITE(6,777) STEP2                                                CFL 0420
  777 FORMAT('0',4X,'THIS RUN USED VARIABLE STEP SIZE',/,'0',4X,'THE MINCFL 0430
     1IMUM STEPSIZE RECORDED DURING THE RUN WAS',2X,E30.5)              CFL 0440
    1 ENDFILE 1                                                         CFL 0450
      REWIND 1                                                          CFL 0460
      TITLE(7)=LINE2(1)                                                 CFL 0470
      TITLE(10)=LINE2(2)                                                CFL 0480
      IF(NGRAF.EQ.0) GO TO 11                                           CFL 0490
      J=1                                                               CFL 0500
      NGF=NGRAF                                                         CFL 0510
      INDEX=NGRAF*2                                                     CFL 0520
      DO 19 I=1,INDEX,2                                                 CFL 0530
      INDX=NXYS(I)                                                      CFL 0540
      INDY=NXYS(I+1)                                                    CFL 0550
      IQ=0                                                              CFL 0560
    7 READ(1,END=8)TIME,ETA,Z,THETA,PB,BOWACC,ACC,FANPWR,PHI,BETAS,ACCLACFL 0570
     1T,U,TRADUS,R,X,Y,QIN,QOUT,GFXXX,FXPWAV,GF2,GF3,GF4,GF5,GF6,DELRS  CFL 0580
      IF(IQ.GE.900) GO TO 8                                             CFL 0590
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      IQ=IQ+1
      XOUT(IQ)=PVQQ(INDX)
      YOUT(IQ)=PVQQ(INDY)
      GO TO 7
    8 REWIND 1
      INX=INDX*2
      INY=INDY*2
      NAMEX(1)=NAMES(INX-1)
      NAMEX(2)=NAMES(INX)
      NAMEY(1)=NAMES(INY-1)
      NAMEY(2)=NAMES(INY)
      IF(NDRW.EQ.1) GO TO 20
      CALL PLOTP(XOUT,YOUT,-IQ,0)
      WRITE(6,301) NAMEX,NAMEY
  301 FORMAT(' ',20X,2A8,' IS THE INDEPENDENT VARIABLE AND ',2A8,' THE D
     1EPENDENT VARIABLE')
      GO TO 19
   20 TITLE(8)=NAMEY(1)
      TITLE(9)=NAMEY(2)
      TITLE(11)=NAMEX(1)
      TITLE(12)=NAMEX(2)
      NCUR=NCURV(J)
      IF(NCUR.NE.0) GO TO 25
      LABEL=LAB(1)
      CALL DRAW(IQ,XOUT,YOUT,NCUR,0,LABEL,TITLE,0,0,0,0,0,0,8,8,0,LAST)
      J=J+1
      GO TO 19
   25 WRITE(2)IQ,NCUR,NGF,LABEL,(TITLE(K),K=1,12),(XOUT(L),YOUT(L),L=1,I
     1Q)
      NGF=NGF-1
   19 CONTINUE
      IF((NGF.EQ.0).AND.(NCUR.EQ.3)) GO TO 26
   11 IF(IVERT.NE.1) GO TO 14
      WRITE(6,100)
  100 FORMAT('0',50X,'***SUMMARY ONE***',/,'0')
      K=0
      DO 31 I=1,8
      IF(ISUM1(I).NE.0) K=K+1
   31 CONTINUE
      NUM1=K
      IF(K.EQ.0) GO TO 14
      N=K*2
      J=1
      DO 33 I=1,NUM1
      IDEX=ISUM1(I)*2
      INAME(J)=NAMES(IDEX-1)
      INAME(J+1)=NAMES(IDEX)
      J=J+2
```

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   33 CONTINUE                                                                CFL 1080
      WRITE(6,300)(INAME(I),I=1,N)                                            CFL 1090
  300 FORMAT('0',16A8)                                                        CFL 1100
      GO TO 4                                                                 CFL 1110
   26 ENDFILE 2                                                               CFL 1120
      REWIND 2                                                                CFL 1130
      NGF=NGRAF                                                               CFL 1140
      J=1                                                                     CFL 1150
   27 READ(2,END=38)IQ,NCUR,NGRAF,LABEL,(TITLE(K),K=1,12),(XOUT(L),YOUT(CFL 1160
     1L),L=1,IQ)                                                              CFL 1170
      IF((NGF.EQ.NGRAF).AND.(NCUR.EQ.J)) GO TO 29                             CFL 1180
      GO TO 27                                                                CFL 1190
   29 LABEL=LAB(J+1)                                                          CFL 1200
      CALL DRAW(IQ,XOUT,YOUT,NCUR,0,LABEL,TITLE,0,0,0,0,0,0,8,8,0,LAST) CFL 1210
      REWIND 2                                                                CFL 1220
      J=J+1                                                                   CFL 1230
      IF(J.EQ.4) GO TO 38                                                     CFL 1240
      GO TO 27                                                                CFL 1250
   38 NGF=NGF-1                                                               CFL 1260
      IF(NGF.EQ.0) GO TO 11                                                   CFL 1270
      J=1                                                                     CFL 1280
      GO TO 27                                                                CFL 1290
    4 READ(1,END=13)(PVQQ(I),I=1,26)                                          CFL 1300
      DO 35 I=1,NUM1                                                          CFL 1310
      J=ISUM1(I)                                                              CFL 1320
   35 AFILE(I)=PVQQ(J)                                                        CFL 1330
      WRITE(6,400)(AFILE(I),I=1,NUM1)                                         CFL 1340
  400 FORMAT('0',8(3X,F10.2,3X))                                              CFL 1350
      GO TO 4                                                                 CFL 1360
   13 REWIND 1                                                                CFL 1370
   14 IF(ILATRL.NE.1) GO TO 17                                                CFL 1380
      WRITE(6,200)                                                            CFL 1390
  200 FORMAT('0',50X,'***SUMMARY TWO***',/,'0')                               CFL 1400
      K=0                                                                     CFL 1410
      DO 32 I=1,8                                                             CFL 1420
      IF(ISUM2(I).NE.0) K=K+1                                                 CFL 1430
   32 CONTINUE                                                                CFL 1440
      NUM2=K                                                                  CFL 1450
      IF(K.EQ.0) GO TO 16                                                     CFL 1460
      N=K*2                                                                   CFL 1470
      J=1                                                                     CFL 1480
      DO 34 I=1,NUM2                                                          CFL 1490
      IDEX= ISUM2(I)*2                                                        CFL 1500
      INAME(J)=NAMES(IDEX-1)                                                  CFL 1510
      INAME(J+1)=NAMES(IDEX)                                                  CFL 1520
      J=J+2                                                                   CFL 1530
   34 CONTINUE                                                                CFL 1540
      WRITE(6,300)(INAME(I),I=1,N)                                            CFL 1550
```

```
   23 READ(1,END=16)(PVQQ(I),I=1,26)                                  CFL 1560
      DO 36 I=1,NUM2                                                  CFL 1570
      J=ISUM2(I)                                                      CFL 1580
   36 AFILE(I)=PVQQ(J)                                                CFL 1590
      WRITE(6,400)(AFILE(I),I=1,NUM2)                                 CFL 1600
      GO TO 23                                                        CFL 1610
   16 REWIND 1                                                        CFL 1620
   17 RETURN                                                          CFL 1630
      END                                                             CFL 1640
C
C                                                                     DMV 0010
      SUBROUTINE DMINV (A,N,D)                                        DMV 0020
      DIMENSION A(6,6),PIVOT(6)                                       DMV 0030
      DIMENSION IPVOT(6),INDEX(6,2)                                   DMV 0040
      EQUIVALENCE (IROW,JROW),(ICOL,JCOL)                             DMV 0050
      D=1.0                                                           DMV 0060
      DO 17 J=1,N                                                     DMV 0070
      IPVOT(J)=0                                                      DMV 0080
   17 CONTINUE                                                        DMV 0090
      DO 135 I=1,N                                                    DMV 0100
      T=0.0                                                           DMV 0110
        DO 9 J=1,N                                                    DMV 0120
      IF(IPVOT(J)-1) 13,9,13                                          DMV 0130
   13 DO 23 K=1,N                                                     DMV 0140
      IF(IPVOT(K)-1) 43,23,81                                         DMV 0150
   43 IF (ABS(T)-ABS(A(J,K))) 83,23,23                                DMV 0160
   83 IROW=J                                                          DMV 0170
      ICOL=K                                                          DMV 0180
      T=A(J,K)                                                        DMV 0190
   23 CONTINUE                                                        DMV 0200
    9 CONTINUE                                                        DMV 0210
      IPVOT(ICOL)=IPVOT(ICOL)+1                                       DMV 0220
      IF(IROW-ICOL) 73,109,73                                         DMV 0230
   73 D=-D                                                            DMV 0240
      DO 12 L=1,N                                                     DMV 0250
      T=A(IROW,L)                                                     DMV 0260
      A(IROW,L)=A(ICOL,L)                                             DMV 0270
      A(ICOL,L)=T                                                     DMV 0280
   12 CONTINUE                                                        DMV 0290
  109 INDEX(I,1)=IROW                                                 DMV 0300
      INDEX(I,2)=ICOL                                                 DMV 0310
      PIVOT(I)=A(ICOL,ICOL)                                           DMV 0320
      D=D*PIVOT(I)                                                    DMV 0330
      A(ICOL,ICOL)=1.0                                                DMV 0340
      DO 205 L=1,N                                                    DMV 0350
      A(ICOL,L)=A(ICOL,L)/PIVOT(I)                                    DMV 0360
  205 CONTINUE                                                        DMV 0370
      DO 134 LI=1,N                                                   DMV 0380
```

```
      IF(LI-ICOL) 21,134,21                                            DMV 0390
   21 T=A(LI,ICOL)                                                     DMV 0400
      A(LI,ICOL)=0.0                                                   DMV 0410
      DO 89 L=1,N                                                      DMV 0420
      A(LI,L)=A(LI,L)-A(ICOL,L)*T                                      DMV 0430
   89 CONTINUE                                                         DMV 0440
  134 CONTINUE                                                         DMV 0450
  135 CONTINUE                                                         DMV 0460
      DO 3 I=1,N                                                       DMV 0470
      L=N-I+1                                                          DMV 0480
      IF(INDEX(L,1)-INDEX(L,2)) 19,3,19                                DMV 0490
   19 JROW=INDEX(L,1)                                                  DMV 0500
      JCOL=INDEX(L,2)                                                  DMV 0510
      DO 549 K=1,N                                                     DMV 0520
      T=A(K,JROW)                                                      DMV 0530
      A(K,JROW)=A(K,JCOL)                                              DMV 0540
      A(K,JCOL)=T                                                      DMV 0550
  549 CONTINUE                                                         DMV 0560
    3 CONTINUE                                                         DMV 0570
   81 RETURN                                                           DMV 0580
      END                                                              DMV 0590
C
C                                                                      FAN 0010
      SUBROUTINE FAN                                                   FAN 0020
      INTEGER ON                                                       FAN 0030
      COMMON /AIR/ PINF,RHOINF,GAM                                     FAN 0040
      COMMON /FANMAP/QIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,  FAN 0050
     1 ENSFAN,BRPM,EMRPM,SRPM,NPTSB,NPTSM,NPTSS                        FAN 0060
     2 ,PBFAN(25),PMFAN(25),PSFAN(25),TMEB(25),DELB(25),NB,TMES(25),   FAN 0070
     3DELS(25),NS                                                      FAN 0080
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES, FAN 0090
     -IRUD,IPROP,IAEROD,IRHS                                           FAN 0100
      COMMON/SOFTBS/XBF,PBS,SINBS,COSBS,XBS,ZBS,DELYBS,DPBS,ELMAXB,YAVG FAN 0110
     1B(10)                                                            FAN 0120
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS          FAN 0130
     1 ,ELMAXS,YAVGS(10)                                               FAN 0140
      COMMON /VARBLE/ VAL(40)                                          FAN 0150
      DIMENSION QB(1),QM(1),QS(1),PBOW(1),PM(1),PS(1)                  FAN 0160
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),      FAN 0170
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),    FAN 0180
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),FAN 0190
     3(VAL(24),PB)                                                     FAN 0200
      EQUIVALENCE (VAL(18),FANPWR)                                     FAN 0210
      EQUIVALENCE (QBFAN(1),QB(1)),(QMFAN(1),QM(1)),(QSFAN(1),QS(1)),  FAN 0220
     1 (PBFAN(1),PBOW(1)),(PMFAN(1),PM(1)),(PSFAN(1),PS(1))            FAN 0230
                                                                       FAN 0240
      BRAT=3000/BRPM                                                   FAN 0250
      EMRAT=3000/EMRPM                                                 FAN 0260
```

```
      SRAT=3000/SRPM                                                    FAN 0270
      TL=VAL(1)                                                         FAN 0280
      IF(NB.EQ.0.0) GO TO 5                                             FAN 0290
      DPBS=FG1(TL,NB,TMEB,DELB,ILB)                                     FAN 0300
      PBS=PB+DPBS                                                       FAN 0310
    5 IF(NS.EQ.0.0) GO TO 6                                             FAN 0320
      DPSS=FG1(TL,NS,TMES,DELS,ILS)                                     FAN 0330
      PSS=PB+DPSS                                                       FAN 0340
    6 CONTINUE                                                          FAN 0350
      PB1=PBS-PINF                                                      FAN 0360
      PB2=PB-PINF                                                       FAN 0370
      PB3=PSS-PINF                                                      FAN 0380
      PBARB=PB1*BRAT**2                                                 FAN 0390
      PBARM=PB2*EMRAT**2                                                FAN 0400
      PBARS=PB3*SRAT**2                                                 FAN 0410
                                                                        FAN 0420
      QBOW=ENBFAN*FG1(PBARB,NPTSB,PBOW,QB,IB)/BRAT                      FAN 0430
      QMAIN=ENMFAN*FG1(PBARM,NPTSM,PM,QM,IM)/EMRAT                      FAN 0440
      QSTN=ENSFAN*FG1(PBARS,NPTSS,PS,QS,IS)/SRAT                        FAN 0450
      QIN=QBOW+QMAIN+QSTN                                               FAN 0460
      FANPWR=(QBOW*PB1+QMAIN*PB2+QSTN*PB3)/550.                         FAN 0470
      IF (IRHS.NE.ON) RETURN                                            FAN 0480
      WRITE(6,100) QBOW,QMAIN,QSTN,PBARB,PBARM,PBARS                    FAN 0490
  100 FORMAT(//4H FAN /32H Q - BOW,MAIN,STERN (CU FT /SEC) 3F12.1       FAN 0500
     1 /28H DELP - BOW,MAIN,STERN (PSF) 3F11.2)                         FAN 0510
      RETURN                                                            FAN 0520
      END                                                               FAN 0530
C
C
C                                                                       FG1 0010
      FUNCTION FG1(X,N,XT,YT,IX)                                        FG1 0020
      DIMENSION XT(1),YT(1)                                             FG1 0030
      IF (IX.LT.1) IX=1                                                 FG1 0040
      IF (IX.GT.N-1) IX=N-1                                             FG1 0050
      I=SIGN(1.0,X-XT(IX))                                              FG1 0060
 10   IF (IX.LT.1 .OR. IX.GE.N) GO TO 30                                FG1 0070
      IF (XT(IX).GT.X .OR. X.GT.XT(IX+1)) GO TO 20                      FG1 0080
      C=(X-XT(IX))/(XT(IX+1)-XT(IX))                                    FG1 0090
      GO TO 100                                                         FG1 0100
 20   IX=IX+I                                                           FG1 0110
      GO TO 10                                                          FG1 0120
 30   C=IX/N                                                            FG1 0130
      IX=IX-I                                                           FG1 0140
 100  FG1=YT(IX)+C*(YT(IX+1)-YT(IX))                                    FG1 0150
      RETURN                                                            FG1 0160
      END                                                               FG1 0170
C
C                                                                       FRT 0010
```

```
      SUBROUTINE FORIT(FNT,N,M,A,B,IER)

      DIMENSION A(1),B(1),FNT(1)

C     CHECK FOR PARAMETER ERRORS
      IER=0
20    IF(M) 30,40,40
30    IER=2
      RETURN
40    IF(M-N) 60,60,50
50    IER=1
      RETURN

C     COMPUTE AND PRESET CONSTANTS
 60   CONTINUE
      AN=N
      COEF=2.0/(2.0*AN+1.0)
      PI=4.*ATAN(1.)
      CONST=PI*COEF
      S1=SIN(CONST)
      C1=COS(CONST)
      C=1.0
      S=0.0
      J=1
      FNTZ=FNT(1)
70    U2=0.0
      U1=0.0
      I=2*N+1

C     FORM FOURIER COEFFICIENTS RECURSIVELY
75    U0=FNT(I)+2.0*C*U1-U2
      U2=U1
      U1=U0
      I=I-1
      IF(I-1) 80,80,75
80    A(J)=COEF *(FNTZ+ C*U1-U2)
      B(J)=COEF*S*U1
      IF(J-(M+1)) 90,100,100
90    Q=C1*C-S1*S
      S=C1*S+S1*C
      C=Q
      J=J+1
      GO TO 70

100   A(1)=A(1)*0.5
      RETURN
      END
C
```

```
C
      SUBROUTINE INCON (TIME)
      REAL*8 TICRD
      INTEGER ON
      COMMON /AIR/ PINF,RHOINF,GAM
      COMMON/AXIS/NXYS(26)
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IY
      COMMON /COLUMN/ IVERT,ILATRL
      COMMON /CONST/ PI,RAD,UO
      COMMON /CNTRL/CONTW,CONTQ,CONTTH,QMULT,LCUVER,ACONTZ,ACONTW,ZEQUIL
     1 ,THEQL,ACBASE
      COMMON /CURVE/NCURV(10)
      COMMON/ENGINE/NPS,NPP,THSTS(25),THSTP(25),XP,YP,ZP,STHS,STHP,
     ATIP(25),TIS(25)
      COMMON /EQNCO/ NEQS,TCL(20),JQQ
      COMMON /FAIR/ RHOA,XLAERO
      COMMON /FANMAP/QIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,
     1 ENSFAN,BRPM,EMRPM,SRPM,NPTSB,NPTSM,NPTSS
     2 ,PBFAN(25),PMFAN(25),PSFAN(25),TMEB(25),DELB(25),NB,TMES(25),
     3DFTS(25),NS
      COMMON / FROUDE / FN,FNCRIT
      COMMON/GBOW/ XBOW
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VCLNOM
     1,DELS(4,10),XCP,ZCP
      COMMON /GEOMSW/ XAVG(10),DS
      COMMON/GRAF/NGRAF,NDRW
      COMMON /HEADG/TICRD(6)
      COMMON /PWAVE/ FNCON,PWVCON
      COMMON/LEAKER/ALEAK,BLEAK,CFSS,CFBS
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHC,NMASS,
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO
      COMMON /MATRIX/ A(6,6)
      COMMON /OPTION/ I3DOF,ISRGE,ITRIM
      COMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT
      COMMON/PLVCQQ/NVI,NVD,NLI,NLD
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,
     -IRUD,IPROP,IAEROD,IRHS
      COMMON /ROLL/ PHIMAX,TROLL
      COMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRDS,TL,RSPAN,RAREA,RASPR,
     ARCLB,RTC,RUDANG,TIR(25)
      COMMON /RISER/ AMPTC
      COMMON/SOFTBS/XBF,PBS,SINBS,COSBS,XBS,ZBS,DELYBS,DPBS,ELMAXB,YAVG
     1B(10)
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS
     1 ,ELMAXS,YAVGS(10)
      COMMON /SIDE/FXSW,FYSW,FZSW,FKSW,FMSW,FNSW,ALSW,YSW,XLSW,CFSW,CDSW
     1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC
```

```
      COMMON /STABLE/ S(4),ISTAB
      COMMON /STSLR/ CPHI,CPHID
      COMMON /SUM/ ISUM1(8),ISUM2(8)
      COMMON / VALOLD / YOLD(20)
      COMMON /VARBLE/ VAL(40)
      COMMON /WAVE/ ETA(4,11),AW(10),CMEGA(10),CVOLW,NWAVE,BETA,
     1            FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV
     2            ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR
      COMMON /WAVEF/WAVLEN(10),OMEGAE(10),WAVSLP(10),ENCPER(10)
      COMMON /WAVTAB/ NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB,
     1          AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),
     2          AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)
     3          ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),
     4          AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),
     5          AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)
     6          ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7)
     7          ,BB(36),XREF,RX

      DIMENSION ZZZ(14050)
      EQUIVALENCE (ZZZ,NAL)
      EQUIVALENCE             (VAL(2),U),(VAL(3),V),(VAL(4),W),
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),
     3(VAL(24),PB)
      DIMENSION TEMP(7),XMO(10)
      DIMENSION TITLC(20)
      DATA BEAM,BETAD,DELO,DELPI,DLRDO,DSO,ISYS,RMAXO,RONC,RRATO,RREVO,
     1 THETO,THSSI,TPRINO,UC,VXO,VZO,XBSI,XCPO,XLTOT,XPO,XRO,XSSI,YPO,
     2 ZPO,ZRO,ZSSI/ 6*0.0,0,20*0.0/
      DO 9 I=1,8
      ISUM1(I)=0
    9 ISUM2(I)=0
      PINF=2116.
      RHOINF=.002378
      GAM=1.4
      GO TO 10
 2200 READ(5,3000) NGRAF,NDRW
 3000 FORMAT(2I2)
      READ(5,3001) NXYS
 3001 FORMAT(26I2)
      READ(5,3002) TICRD
 3002 FORMAT(6A8)
 10   READ(5,99) ISYSL,IOPT,(TEMP(I),I=1,7)
      IF( ISYSL .EQ. ISYS .AND. ISYSL.EQ. 13) GOTO 70
      ISYS=ISYSL
      IF((ISYS.LE.0).OR.(ISYS.GT.22)) GO TO 70
      GOTO(100,200,300,400,500,600,700,800,900,1000,1100,1200,1300,
     11400,1500,1600,1700,1800,1900,2000,2100,2200),ISYS
```

```
C       PROGRAM CONTROL PARAMETERS
100     CCNTINUE
        GOTO (101,102,103,104,105),IOPT
 101    CONTINUE
        STIME=TEMP(1)
        FTIME=TEMP(2)
        DELO=TEMP(3)
        DELPNT=TEMP(4)
        TPRINO=TEMP(5)
        IF (TPRINO.LT.STIME+DELPNT) TPRINO = STIME+DELPNT
        IF (DELO.GT.DELPNT) DFLO=DELPNT
        IF (DELO.EQ.0.0) GO TO 140
        GCTO 10
 2000   READ(5,3003) NCURV
 3003   FCRMAT(10I1)
        GC TO 10
 2100   READ(5,2210) ISUM1
        READ(5,2210)ISUM2
 2210   FCRMAT(8I2)
        GO TO 10
102     READ (5,191) IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,IRUD,
     1  IPROP,IAEROD,IRHS
        GCTO 10
103     READ (5,175) NEQS,JQQ,(TOL(J),J=1,NEQS)
        GOTO 10
 104    READ(5,191) IVERT,ILATRL,NVD,NVI,NLD,NLI
        GC TO 10
 105    CONTINUE
        I3DOF=TEMP(1)
        ISRGE=TEMP(2)
        ITRIM=TEMP(3)
        GC TO 10
  140   WRITE(6,195)
        STOP
C       MASS DISTRIBUTION
  200   G=32.17
        RHC=1.99
        HRHO=RHO/2.
        GC TO (210,220,230), IOPT
  210   IMM = 0
        WEIGHT = TEMP(1)
        AM = WEIGHT/G
        XS = TEMP(2)
        ZS = TEMP(3)
        AIXX = TEMP(4)
        AIYY = TEMP(5)
```

```
      AIZZ = TEMP(6)
      AIXZ = TEMP(7)
C     INERTIA MATRIX OPERATIONS
  212 DO 211 I=1,6
      DO 211 N=1,6
  211 A(I,N) = 0.0
      DO 213 N=1,3
  213 A(N,N)=AM
      A(4,4)=AIXX
      A(5,5)=AIYY
      A(6,6)=AIZZ
      A(4,6)=-AIXZ
      A(6,4)=-AIXZ
      AIMAX=AMAX1(AM,AIXX,AIYY,AIZZ,ABS(AIXZ))
      DO 214 I=1,6
      DO 214 J=1,6
  214 A(I,J)=A(I,J)/AIMAX
      CALL DMINV (A,6,D)
      DO 215 I=1,6
      DO 215 J=1,6
  215 A(I,J)=A(I,J)/AIMAX
      IF (D.NE.0.0) GO TO 10
      WRITE (6,216)
      STOP
C     READ WEIGHT DISTRIBUTION - ASSUME TRANSVERSE (PORT/STBD) SYMMETRY
C        X INPUT DIST. FWD. OF (SIDEWALL) TRANSCM
C        Y INPUT DIST. TO STARBOARD
  220 I = 1
C        Z INPUT DIST. UP FROM KEEL-LINE
  222 READ (5,192) AMI(I),XI(I),YI(I),ZI(I)
      IF (AMI(I).LT.0.0)  GO TO 224
      I = I+1
      IF ( I.GT.201 )  GO TO 70
      GO TO 222
  224 NMASS = I-1
      SUM = 0.0
      SUX = 0.0
      SUZ = 0.0
      DO 225 I=1,NMASS
      AMI(I) = AMI(I)/G
      SUM = SUM+AMI(I)
      SUX = SUX+AMI(I)*XI(I)
  225 SUZ = SUZ+AMI(I)*ZI(I)
      AM = SUM*2.0
      WEIGHT = AM*G
      ZS  = SUZ/SUM
      XS  = SUX/SUM
      SUM = 0.0
```

```
      SUX = 0.0
      SUY = 0.0
      SUZ = 0.0
      DO 226 I=1,NMASS
      XI(I) = XI(I)-XS
      ZI(I) = -ZI(I)+ZS
      AMK = AMI(I)*2.0
      SUX = SUX+AMK*XI(I)*XI(I)
      SUY = SUY+AMK*YI(I)*YI(I)
      SUZ = SUZ+AMK*ZI(I)*ZI(I)
  226 SUM = SUM+AMK*XI(I)*ZI(I)
      AIXX = SUY+SUZ
      AIYY = SUX+SUZ
      AIZZ = SUX+SUY
      AIXZ = SUM
      GO TO 212
  230 GO TO 10
C     XX AND YY TABLES
300   CONTINUE
      NSTA(1) = TEMP(1)
      NSTA(2) = TEMP(2)
      NSTA(3) = TEMP(3)
      NSTA(4) = TEMP(4)
      XLTOT=TEMP(5)
      GOTO 10
C     SIDEWALL (INCLUDING APPENDAGES)
400   CONTINUE
      GOTO (401,402),IOPT
401   YSW=TEMP(1)
      XLSW=TEMP(2)
      CFSW=TEMP(3)
      CDSW=TEMP(4)
      AVBMSW=TEMP(5)
      READ (10) ZZZ
      REWIND 10
      GOTO 10
C    BLOCK 4 OPTION 2 REMOVED.       NO APENDAGES
  402 CONTINUE
      GOTO 10
C     STERNSEAL
500   CONTINUE
      XSSI=TEMP(1)
      ZSSI=TEMP(2)
      ALEAK=TEMP(3)
      CFSS=TEMP(4)
```

```
      THSSI=TEMP(5)                                                     INC 2410
      DPSS=TEMP(6)                                                      INC 2420
      XLF=TEMP(7)                                                       INC 2430
      SINTH=SIN(THSSI/RAD)                                              INC 2440
      COSTH=COS(THSSI/RAD)                                              INC 2450
      ELMAXS=XLF*COSTH                                                  INC 2460
      GC TO 10                                                          INC 2470
                                                                        INC 2480
C     BOWSEAL                                                           INC 2490
600   CCNTINUE                                                          INC 2500
      XBSI=TEMP(1)                                                      INC 2510
      CFBS=TEMP(2)                                                      INC 2520
      DPBS=TEMP(3)                                                      INC 2530
      ZBSI=TEMP(4)                                                      INC 2540
      THBSI=TEMP(5)                                                     INC 2550
      XBF=TEMP(6)                                                       INC 2560
      BLEAK=TEMP(7)                                                     INC 2570
      SINBS=SIN(THBSI/RAD)                                              INC 2580
      COSBS=CCS(THBSI/RAD)                                              INC 2590
      ELMAXB=XBF*COSBS                                                  INC 2600
      GCTO 10                                                           INC 2610
                                                                        INC 2620
C     PLENUM                                                            INC 2630
700   CCNTINUE                                                          INC 2640
      GO TO (705,710),IOPT                                              INC 2650
 705  CCNTINUE                                                          INC 2660
      XLBW=TEMP(1)                                                      INC 2670
      XBBW=TEMP(2)                                                      INC 2680
      WIDTH=TEMP(4)                                                     INC 2690
      XL=TEMP(5)                                                        INC 2700
      XCPO=TEMP(6)                                                      INC 2710
      BUBHGT=TEMP(7)                                                    INC 2720
      ABW=XBBW*XLBW                                                     INC 2730
      AB=WIDTH*XL                                                       INC 2740
      VCLNUM=(ABW+AB)*BUBHGT/2.                                         INC 2750
      GOTO 10                                                           INC 2760
 710  CCNTINUE                                                          INC 2770
      FNCRIT=TEMP(1)                                                    INC 2780
      GO TO 10                                                          INC 2790
                                                                        INC 2800
C     PROPULSION                                                        INC 2810
800   CONTINUE                                                          INC 2820
      GC TO (805,810),IOPT                                              INC 2830
 805  CONTINUE                                                          INC 2840
      XPO=TEMP(1)                                                       INC 2850
      YPO=TEMP(2)                                                       INC 2860
      ZPO=TEMP(3)                                                       INC 2870
      GC TO 10                                                          INC 2880
```

```
C BLOCK 8 OPTION 2 REMOVED. ENGINE OUT INPUT IN BLOCK 16
  810 CCNTINUE
      GCTC 10

C     RUDDER
900   CONTINUE
      GC TO (905,910,915),IOPT
  905 XRO = TEMP(1)
      YR=TEMP(2)
      ZRO = TEMP(3)
      RSPAN=TEMP(4)
      RASPR=TEMP(5)
      RAREA=TEMP(6)
      RCLB=2.*PI*RASPR/(RASPR+3.)
      RTC=TEMP(7)
      GC TO 10
C     910 NOT USED
  910 CCNTINUE
      GC TO 10
 915  CONTINUE
      GCTO 10

C     AERODYNAMICS
1000  CONTINUE
      XLAERO=TEMP(1)
      BEAM=TEMP(2)
      RHOA=.5*RHOINF*XLAERO*BEAM
      GOTO 10

C     WAVES
1100  CONTINUE
      IWAVSW=IOPT
      NWAVE=TEMP(1)
      IF(NWAVE .EQ. 0) GOTO 10
      IF(NWAVE .GT. 10) GOTO 70
      BETAD=TEMP(2)
      BETA=BETAD/RAD
      CCSBET=COS(BETA)
      SINBET=SIN(BETA)
      TC = 1.0
      GCTO ( 1104,1106) ,IWAVSW
1104  DO 1105 I=1,NWAVE
1105  READ(5,1190) OMEGA(I),AW(I)
      GCTO 10
1106  DO 1107 I=1,NWAVE
1107  READ (5,1190) WAVLEN(I) ,AW(I)
      GOTO 10
```

```
C       INITIAL CONDITIONS                                                INC 3370
1200    CONTINUE                                                          INC 3380
        UC = TEMP(1)                                                      INC 3390
        THETO = TEMP(2)                                                   INC 3400
        DSO = TEMP(3)                                                     INC 3410
        DELPI=TEMP(4)                                                     INC 3420
        GO TO 10                                                          INC 3430
                                                                          INC 3440
1300    CONTINUE                                                          INC 3450
C       INPUT COMPLETED. 1) PRINT ALL INPUT                               INC 3460
        WRITE(6,2004) TITLC                                               INC 3470
        WRITE (6,2001) STIME,FTIME,DELO,TPRINC,DELPNT                     INC 3480
        WRITE (6,2002) IACCEL,IVEL,ITRAJ,ISIDWL,IBCWSL,ISTNSL,IWAVES,IRUD,INC 3490
      1 IPROP,IAEROD,IRHS                                                 INC 3500
        WRITE(6,2021) I3DOF,ISRGE,ITRIM                                   INC 3510
        WRITE (6,2003) NEQS, (TOL(J),J=1,NEQS)                            INC 3520
        WRITE (6,219) WEIGHT,XS,ZS,AIXX,AIYY,AIZZ,AIXZ                    INC 3530
        WRITE(6,217)A,AIMAX                                               INC 3540
        WRITE (6,2018) NSTA                                               INC 3550
        WRITE (6,490) YSW,XLSW,CFSW,CDSW,VANGLE,VSPAN,VCHORD,VXO,VY,VZO,  INC 3560
      1 AVBMSW,VTC                                                        INC 3570
        WRITE (6,491) NAL,CAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB     INC 3580
        IF (IMM.GT.0)  WRITE(6,1549)    (XMC(J),J=1,IMNX)                 INC 3590
        WRITE (6,1519) IMM,IMNX,IMNY,IBMFIL,BTIME,INT                     INC 3600
        IF (IMM.GT.0)  WRITE(6,1559) (YMI(J),J=1,IMNY)                    INC 3610
        WRITE (6,2010) XLBW,XBBW                                          INC 3620
        WRITE (6,2011) XL,WIDTH,XCPO,VOLNOM,BUBHGT                        INC 3630
        WRITE (6,2020) DELPI                                              INC 3640
        WRITE(6,2009) FNCRIT,XLTOT                                        INC 3650
        WRITE (6,2028) ENBFAN,BRPM,ENMFAN,EMRPM,ENSFAN,SRPM               INC 3660
        WRITE (6,2013) XRO,YR,ZRO,RONO,RMAXO,RRATO,RREVO,DLRDO            INC 3670
      1   ,RSPAN,RASPR,RAREA,RCLB,RTC                                     INC 3680
        WRITE (6,2012)       XPO,YPO,ZPO                                  INC 3690
        WRITE (6,2027) XLAERO,BEAM                                        INC 3700
        WRITE (6,2026) XBSI,CFBS,DPBS,ELMAXB                              INC 3710
        WRITE (6,2025) XSSI,ZSSI,ALEAK,CFSS,THSSI,DPSS,XLF                INC 3720
        WRITE (6,2017) UO,THETO,DSO                                       INC 3730
                                                                          INC 3740
C                 AND 2) INITIALIZE VARIABLES FOR CALCS.                  INC 3750
        DO 1302 I=1,40                                                    INC 3760
 1302   VAL(I) = 0.0                                                      INC 3770
        U = UO 1.6889                                                     INC 3780
        XSS=-(XS-XSSI)                                                    INC 3790
        ZSS=ZS-ZSSI                                                       INC 3800
        THETA = THETO/RAD                                                 INC 3810
        THEQL=THETA                                                       INC.3820
        DS = DSO/12.                                                      INC 3830
        Z=-ZS+DS                                                          INC 3840
```

```
      ZEQUIL=Z
      PHIMAX=0.
      TRCLL=0.
      IRDS=0
      TL=0.0
C     WAVE PARAMETERS TABLE
      IF(NWAVE .EQ.0) GOTO 1321
      AMPTC=1.30287
      GCTO(1310,1315).IWAVSW
1310  DC 1311 I=1,NWAVE
1311  WAVLEN(I)=2.*PI*G/(CMEGA(I)*OMEGA(I))
      GOTO 1317
1315  DO 1316 I=1,NWAVE
1316  CMEGA(I)=SQRT(2.*PI*G/WAVLEN(I))
1317  CONTINUE
C     CALCULATE INITIAL FREQUENCIES OF ENCOUNTER
      DO 1318 I=1,NWAVE
      WAVSLP(I) = 360.0*AW(I)/WAVLEN(I)
      OMEGAE(I) =2.*PI*(SQRT(G*WAVLEN(I)/(2.*PI))-U*COSBET)/WAVLEN(I)
      ENCPER(I) = 2.0*PI/OMEGAE(I)
1318  CCNTINUE
      WRITE (6,1191) NWAVE,BETAD,(OMEGA(I),OMEGAE(I),WAVLEN(I),AW(I),
     1               WAVSLP(I),ENCPER(I),I=1,NWAVE)
      GCTC 1322
 1321 WRITE (6,1192)
1322  CCNTINUE
      DC 1303 I=1,4
      DO 1303 N=1,11
 1303 ETA(I,N) = 0.0
      DVOLW = 0.0
      FXWAV = 0.0
      FYWAV = 0.0
      FZWAV = C.0
      FKWAV = 0.0
      FMWAV = 0.0
      FNWAV = 0.0
      ZBAP=Z
      PHIBAR=PHI
      THEBAR=THETA
      TIME=STIME
      DELT = DELO
      TPRINT=TPRINO-DELPNT
      PWVCON=4.*WEIGHT/(RHO*G*XLBW)
      FNCON=SQRT(XLBW*G)
      VX=VXO-XS
      VZ = ZS-VZO
      XP=XPO-XS
```

```
      XR = XRO-XS                                                       INC 4330
      YP=YPO                                                            INC 4340
      ZP=ZS-ZPO                                                         INC 4350
      ZR = ZS-ZRO                                                       INC 4360
      IF (IMM.EQ. 0) GO TO 1305                                         INC 4370
      DO 1304 J=1,IMNX                                                  INC 4380
 1304 XMI(J) = XMO(J) - XS                                              INC 4390
 1305 CONTINUE                                                          INC 4400
      XCP = XCPO-XS                                                     INC 4410
      ZCP = ZS-BUBHGT                                                   INC 4420
      XBS=XBSI-XS                                                       INC 4430
      N=NSTA(3)                                                         INC 4440
      ZBS=ZS-ZBSI                                                       INC 4450
      DO 1364 J=1,N                                                     INC 4460
      DELYBS=XBBW/(N-1)                                                 INC 4470
       XX(3,J)=XBS-XSSI                                                 INC 4480
      YY(3,J)=-0.5*XBBW+(J-1)*DELYBS                                    INC 4490
 1364 CONTINUE                                                          INC 4500
      N=N-1                                                             INC 4510
      DO 1367 J=1,N                                                     INC 4520
      YAVGB(J)=(YY(3,J+1)+YY(3,J))/2.                                   INC 4530
 1367 CONTINUE                                                          INC 4540
      N=NSTA(4)                                                         INC 4550
      DELYSS=XBBW/(N-1)                                                 INC 4560
      DO 1365 J=1,N                                                     INC 4570
      XX(4,J)=-XS                                                       INC 4580
      YY(4,J)=-.5*XBBW+(J-1)*DELYSS                                     INC 4590
 1365 CONTINUE                                                          INC 4600
      N=N-1                                                             INC 4610
      DO 1368 J=1,N                                                     INC 4620
      YAVGS(J)=(YY(4,J+1)+YY(4,J))/2.                                   INC 4630
 1368 CONTINUE                                                          INC 4640
      XBOW=XLTOT-XS                                                     INC 4650
      N=NSTA(1)                                                         INC 4660
      DELX=XBSI/(N-1)                                                   INC 4670
      DO 1309 J=1,2                                                     INC 4680
      DO 1309 I=1,N                                                     INC 4690
      XX(J,I)=(I-1)*DELX-XS                                             INC 4700
 1309 YY(J,I)= YSW*(2*J-3)                                              INC 4710
      WRITE(6,1366) ((XX(J,N),N=1,11),(YY(J,N),N=1,11),J=1,4)           INC 4720
 1366 FORMAT (//17H XX AND YY ARRAYS /14H PORT SIDEWALL /2(11F10.2/),   INC 4730
     1 15H STBD. SIDEWALL /2(11F10.2/),9H BOW SEAL /2(11F10.2/),        INC 4740
     2 11H STERN SEAL /2(11F10.2/))                                     INC 4750
      N=NSTA(1)-1                                                       INC 4760
      DO 1308 I=1,N                                                     INC 4770
 1308 XAVG(I)=DELX*(2*I-1)/2.-XS                                        INC 4780
      CALL WAVES(TIME)                                                  INC 4790
                                                                        INC 4800
```

```
C     INITIALIZE BUBBLE PRESSURE, ABSOLUTE (PSF)
      PB=PINF+DELPI
      PBEAR=DELPI
      PSS=PB+DPSS
      PBS=PB+DPBS
      AB=XL*(XBBW-(XBBW-WIDTH)*(ZS+Z)/BUBHGT)
      VCL=VOLNOM-.5*(AB+ABW)*(Z+ZS)-DVCLW
      BMASS=(PB/PINF)**(1./GAM)*VCL*RHOINF
      WRITE (6,2023)
      RETURN
C     RUN TERMINATOR
 1400 WRITE(6,98)
      STOP
C     BENDING MOMENT
 1500 GO TO (1510,1520,1530,1540), IOPT
.1510 IMM = TEMP(1)
      IF (IMM.GT.3)  GO TO 70
      IMNX = TEMP(2)
      IF (IMNX.GT.10)  GO TO 70
      IMNY = TEMP(3)
      IF (IMNY.GT.7)  GO TO 70
      IBMFIL = TEMP(4)
      BTIME = TEMP(5)
      IF (IMM.EQ.3)  IMT = TEMP(6)
      GO TO 10
 1520 DO 1521 J=1,7
 1521 XMO(J) = TEMP(J)
      IF (IMNX.LE.7)  GO TO 10
      READ 1522, (XMO(J),J=8,IMNX)
      GO TO 10
 1530 DO 1531 J=1,IMNY
 1531 YMI(J) = TEMP(J)
      GO TO 10
 1540 CONTINUE
      GO TO 10

1600  CONTINUE
      GO TO(1605,1610,1615),IOPT
 1605 CONTINUE
C   VALUES INPUT FOR STBD SCREW
      THST1=TEMP(1)
      NPS=TEMP(2)
      STHS=TEMP(3)
      IF(NPS.EQ.0.0) GO TO 1609
      READ(5,1950)(TIS(J),J=1,NPS)
      READ(5,1950)(THSTS(J),J=1,NPS)
```

```
      GC TO 10
 1609 THSTS(1)=THST1
 1610 CCNTINUE
C   VALUES INPUT FOR PORT SCREW
      THST2=TEMP(1)
      NPP=TEMP(2)
      STHP=TEMP(3)
      IF(NPP.EQ.0.0) GO TO 1614
      READ(5,1950)(TIP(J),J=1,NPP)
      READ(5,1950)(THSTP(J),J=1,NPP)
      GC TO 10
 1614 THSTP(1)=THST2
 1615 CCNTINUE
C   VALUES INPUT FCR RUDDER
      DELR=TEMP(1)
      NPR=TEMP(2)
      IF(NPR.EQ.0.0) GO TO 1616
      READ(5,1950)(TIR(J),J=1,NPR)
      READ(5,1950)(DELRUD(J),J=1,NPR)
      GC TO 10
 1616 DELRUD(1)=DELR
      GO TO 10

 1700 GC TO (1705,1710),ICPT
 1705 NB=TEMP(1)
      READ(5,1950)(TMEB(I),I=1,NB)
      READ(5,1950)(DELB(I),I=1,NB)
      GO TO 10
 1710 NS=TEMP(1)
      READ(5,1950)(TMES(I),I=1,NS)
      READ(5,1950)(DETS(I),I=1,NS)
      GOTO 10

C     TITLE CARD (ALL 80 COLUMNS )
 1800 READ  (5,2022)  TITLC
      GO TO 10

C     FAN MAPS
1900  CCNTINUE
      GC TO (1905,1910,1915),IOPT
1905  CONTINUE
      ENBFAN=TEMP(1)
      BRPM=TEMP(2)
      NPTSB=TEMP(3)
      READIN=TEMP(4)
      IF (READIN .EQ. 0.0) GO TO 10
      READ (5,1950) (PBFAN(J),J=1,NPTSB)
      READ (5,1950) (QBFAN(J),J=1,NPTSB)
```

```
      GC TO 10                                                          INC 5770
 1910 CONTINUE                                                          INC 5780
      ENMFAN=TEMP(1)                                                    INC 5790
      EMRPM=TEMP(2)                                                     INC 5800
      NPTSM=TEMP(3)                                                     INC 5810
      READIN=TEMP(4)                                                    INC 5820
      IF (READIN .EQ. 0.0) GO TO 10                                     INC 5830
      READ (5,1950) (PMFAN(J),J=1,NPTSM)                                INC 5840
      READ (5,1950) (QMFAN(J),J=1,NPTSM)                                INC 5850
      GC TO 10                                                          INC 5860
 1915 CONTINUE                                                          INC 5870
      ENSFAN=TEMP(1)                                                    INC 5880
      SRPM=TEMP(2)                                                      INC 5890
      NPTSS=TEMP(3)                                                     INC 5900
      READIN=TEMP(4)                                                    INC 5910
      IF (READIN .EQ. 0.0) GO TO 10                                     INC 5920
      READ (5,1950) (PSFAN(J),J=1,NPTSS)                                INC 5930
      READ (5,1950) (QSFAN(J),J=1,NPTSS)                                INC 5940
      GC TO 10                                                          INC 5950
 1950 FORMAT(8F10.0)                                                    INC 5960
C     ERROR IN INPUT                                                    INC 5970
   70 CONTINUE                                                          INC 5980
      WRITE (6,79) ISYS                                                 INC 5990
      STOP                                                              INC 6000
   79 FORMAT(34H INPUT ERROR - - - STOP - -  ISYS= ,I3)                 INC 6010
   98 FORMAT(1H1,20(/),50X,19H COMPLETED ALL RUNS )                     INC 6020
99    FORMAT(I3,I2,7F10.0)                                              INC 6030
  191 FORMAT (16I5)                                                     INC 6040
  192 FORMAT (5F10.0)                                                   INC 6050
  195 FORMAT(///10X,65HERROR IN INPUT --- DELT AND/OR DELPNT EQUALS ZEROINC 6060
     1 --- JOB ABORTED )                                                INC 6070
  175 FORMAT (2I2/(8F10.0))                                             INC 6080
  216 FORMAT(///10X,82HERROR IN INPUT --- INPUT INERTIA ELEMENTS LEAD TOINC 6090
     1 ZERO DETERMINANT --- JOB ABORTED )                               INC 6100
  217 FORMAT(22H INERTIA MATRIX, AIMAX  6E15.4/(22X,6E15.4))            INC 6110
  219 FORMAT(30H WEIGHT, C.G., INERTIA MOMENTS 7F12.3)                  INC 6120
  305 FORMAT ( 11F7.0 )                                                 INC 6130
  490 FORMAT(15H SIDEWALL INPUT 12(F8.3,1X))                            INC 6140
  491 FORMAT(26H SIDEWALL TABLE PARAMETERS 4(I4,F7.3,F7.3))             INC 6150
 1190 FORMAT(2F10.0)                                                    INC 6160
 1191 FORMAT(/12HONO OF WAVES I2,10H BETA(DEG)F5.0/15H OMEGA(RAD/SEC) , INC 6170
     15X,16H OMEGAE(RAD/SEC) 5X,16H WAVE LENGTH(FT) 5X,14H AMPLITUDE(FT)INC 6180
     - 5X,16HMAX  SLOPE (DEG)5X,13HPERIOD,E(SEC)/(F8.4,12X,F8.4,4F20.3))INC 6190
 1192 FORMAT(/11HOCALM WATER)                                           INC 6200
 1519 FORMAT(32HOMOMENT CALC. CONTROL PARAMETERS 4I5, F8.3, I5 )        INC 6210
 1522 FORMAT ( 5X,7F10.0)                                               INC 6220
 1549 FORMAT(22H MOMENT CALCS. AT X OF 11F10.3)                         INC 6230
 1559 FORMAT(22H MOMENT CALCS. AT Y OF 11F10.3)                         INC 6240
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2004 FORMAT(33H1SES MOTIONS AND LOADS PROGRAM - 20A4,/)                   INC 6250
2001 FORMAT(23H START AND FINISH TIMES 2F10.2/                              INC 6260
    -22H INITIAL TIME INTERVAL F12.4/                                       INC 6270
    -18H START PRINTING AT F8.2,17H IN INCREMENTS OF F8.2)                  INC 6280
2002 FORMAT(24H INTERMEDIATE PRINT TAGS 16I5)                               INC 6290
2003 FORMAT(39H NO. OF STATE EQUATIONS, AND TOLERANCESI5/(10X,10E12.2))INC 6300
2009 FORMAT(23H0CRITICAL FROUDE NUMBER F15.4,5X,19H TOTAL CRAFT LENGTH INC 6310
   1        F15.4)                                                          INC 6320
2010 FORMAT(34H0PLENUM, LENGTH AND WIDTH AT WATER 2F12.4)                   INC 6330
2011 FORMAT(34H PLENUM, LENGTH AND WIDTH AT HULL  2F12.4/                   INC 6340
    -       35H PLENUM, CENTER OF PRESSURE AT HULL F12.4/                   INC 6350
    -23H PLENUM, NOMINAL VOLUME F12.1,10X, 6HHEIGHT F12.4)                  INC 6360
2012 FORMAT(/33H PROPULSION, X, Y, Z COORDINATES  3F12.4/)                  INC 6370
2013 FORMAT(/28H0RUDDER, X, Y, Z COORDINATES  3F12.4/                       INC 6380
    -        41H RUDDER, ON, MAX, RATE, REVERSE, INITIAL  5F12.4/           INC 6390
    -        33H RUDDER,SPAN,ASPECT,AREA,CLB,T/C  5F12.4)                   INC 6400
2017 FORMAT(/39H0INITIAL CONDITIONS, VELOCITY (KNOTS) = F7.2, 5X,           INC 6410
    -        13HPITCH (DEG) = F8.3,5X,12HDRAFT (IN) = F8.2)                 INC 6420
2018 FORMAT( 49H NUMBER OF STATIONS, SIDEWALLS (P+S), SEALS (B+S) ,4I5)INC 6430
2020 FORMAT( 38H PLENUM, INITIAL PRESSURE, GAGE (PSF)  F8.2)                INC 6440
2021 FORMAT(70H PROGRAM OPTION SWITCH SETTINGS (LATERAL PLANE,CONSTANT INC 6450
    -SPEED,TRIM)          3I5)                                              INC 6460
2022 FORMAT (20A4 )                                                         INC 6470
2023 FORMAT ( 1H1 )                                                         INC 6480
2025 FORMAT( 16H STERNSEAL INPUT   7F12.4 )                                 INC 6490
2026 FORMAT( 16H BOWSEAL INPUT     7F12.4 )                                 INC 6500
2027 FORMAT( 19H0AERODYNAMICS INPUT  7F12.4)                                INC 6510
2028 FORMAT( 33H0FANS, NO. + RPM, BOW,MAIN,STERN  3(F10.0,F10.1))           INC 6520
     END                                                                    INC 6530
C
C                                                                           INT 0010
      SUBROUTINE INTGRL (TIME)                                              INT 0020
      INTEGER ON                                                            INT 0030
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IYINT 0040
      COMMON /EQNCO/ NEQS,TOL(20),JQQ                                       INT 0050
      COMMON /KSWTCH/ ITHRST                                                INT 0060
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,      INT 0070
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO           INT 0080
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT                         INT 0090
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,      INT 0100
     -IRUD,IPROP,IAEROD,IRHS                                                INT 0110
      COMMON /STABLE/ S(4),ISTAB                                            INT 0120
      COMMON/STEP/ STEP2                                                    INT 0130
      COMMON / VALOLD / YOLD(20)                                            INT 0140
      COMMON /VARBLE/ VAL(40)                                               INT 0150
                                                                            INT 0160
      EQUIVALENCE (VAL(1),X),(VAL(2),Y(1))                                  INT 0170
      DIMENSION Y(20),ERROR(20)                                             INT 0180
```

```
      REAL K1(20),K2(20),K3(20),K4(20),K5(20)                    INT 0190
      DATA IPASS/0/                                              INT 0200
                                                                 INT 0210
      STEP2=1.0                                                  INT 0220
    1 IF((TIME+DELT).LE.TPRINT) GO TO 12                         INT 0230
      DEL=DELT                                                   INT 0240
      DELT=TPRINT-TIME                                           INT 0250
      IPASS=1                                                    INT 0260
   12 X=TIME                                                     INT 0270
      DO 2 J=1,NEQS                                              INT 0280
      Y(J)=YOLD(J)                                               INT 0290
    2 CONTINUE                                                   INT 0300
      ITHRST=1                                                   INT 0310
      CALL RHS(K1)                                               INT 0320
      ITHRST=2                                                   INT 0330
      INT = 0                                                    INT 0340
      IF (IACCEL.NE. ON) GO TO 14                                INT 0350
      ACCLAT = (K1(2)+Y(1)*Y(6))/G                               INT 0360
      WRITE  (6,101)  ACCLAT , DELT                              INT 0370
14    ON=2                                                       INT 0380
 15   H=DELT/3.                                                  INT 0390
      X=TIME+H                                                   INT 0400
      DO 3 J=1,NEQS                                              INT 0410
    3 Y(J)=YOLD(J)+H*K1(J)                                       INT 0420
      CALL RHS(K2)                                               INT 0430
      DO 4 J=1,NEQS                                              INT 0440
    4 Y(J)=YOLD(J)+.5*H*(K1(J)+K2(J))                            INT 0450
      CALL RHS(K3)                                               INT 0460
      X=TIME+.5*DELT                                             INT 0470
      DO 5 J=1,NEQS                                              INT 0480
    5 Y(J)=YOLD(J)+.375*H*(K1(J)+3.*K3(J))                       INT 0490
      CALL RHS(K4)                                               INT 0500
      X=TIME+DELT                                                INT 0510
      DO 6 J=1,NEQS                                              INT 0520
    6 Y(J)=YOLD(J)+.5*H*(3.*K1(J)-9.*K3(J)+12.*K4(J))            INT 0530
      CALL RHS(K5)                                               INT 0540
      IF (JQQ.EQ. 1 ) GO TO 7                                    INT 0550
      DO 7 J=1,NEQS                                              INT 0560
      ERROR(J)=(K1(J)-4.5*K3(J)+4.*K4(J)-.5*K5(J))*H/5.0         INT 0570
      IF(ABS(ERROR(J)).GT.TOL(J)) GO TO 11                       INT 0580
    7 CONTINUE                                                   INT 0590
      DO 105 J=1,NEQS                                            INT 0600
      Y(J)=YOLD(J)+.5*H*(K1(J)+4.*K4(J)+K5(J))                   INT 0610
105   YOLD(J)=Y(J)                                               INT 0620
      TIME=TIME+DELT                                             INT 0630
      IF (IPASS.EQ.1) GO TO 8                                    INT 0640
      IF (JQQ.EQ. 1 ) GO TO 10                                   INT 0650
      DO 75 J=1,NEQS                                             INT 0660
```

```
      IF(ABS(ERROR(J)).GT.TOL(J)/16.) GC TO 9                           INT 0670
   75 CONTINUE                                                          INT 0680
      DELT=2.*DELT                                                      INT 0690
      IF (DELT.GT.DELPNT) DELT=DELPNT                                   INT 0700
   10 RETURN                                                            INT 0710
    9 STEP2=DELT                                                        INT 0720
      GO TO 10                                                          INT 0730
    8 DELT=DEL                                                          INT 0740
      IPASS=0                                                           INT 0750
      GO TO 10                                                          INT 0760
  11  DELT=DELT/2.                                                      INT 0770
      IF (DELT.LT. 1.E-6 )  GO TO 25                                    INT 0780
      IF(JQQ.EQ.2) GO TO 26                                             INT 0790
                         WRITE (6,666) TIME,DELT,J,ERROR(J),TOL(J)      INT 0800
   27 IPASS=0                                                           INT 0810
      GC TO 15                                                          INT 0820
   26 STEP1=DELT/2.0                                                    INT 0830
      IF(STEP1.LT.STEP2)STEP2=STEP1                                     INT 0840
      GC TO 27                                                          INT 0850
   25 WRITE ( 6,150 )                                                   INT 0860
      WRITE (6,100) TIME,DELT,(K1(J),J=1,NEQS),VAL                      INT 0870
      STOP                                                              INT 0880
  100 FORMAT(/10X,23HINTGRL TIME,DELT,K1,VAL /2E15.4/2(5E15.4/),5(8E15.4INT 0890
     1))                                                                INT 0900
  101 FORMAT(1H0,9X,33HTOTAL LATERAL ACCELERATION (G) =    F12.4,       INT 0910
     112X,5HDT =  E15.4)                                                INT 0920
  150 FORMAT(1H1,10X,44HDELTA TIME LESS THAN 1.0E-6  -  -  JOB STOPS )  INT 0930
  666 FORMAT(/10X,5HINT-J 2E30.5,I5,2E20.5)                             INT 0940
      END                                                               INT 0950
C
C                                                                       PRP 0010
      SUBROUTINE PROP                                                   PRP 0020
      INTEGER ON                                                        PRP 0030
      COMMON /CONST/ PI,RAD,UO                                          PRP 0040
      COMMON /FPROP/ FX,FY,FZ,FK,FM,FN                                  PRP 0050
      CCMMON/ENGINE/NPS,NPP,THSTS(25),THSTP(25),XP,YP,ZP,STHS,STHP,     PRP 0060
     ATIP(25),TIS(25)                                                   PRP 0070
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,  PRP 0080
     -IRUD,IPROP,IAEROD,IRHS                                            PRP 0090
      COMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRCS,TL,RSPAN,RAREA,RASPR,  PRP 0100
     ARCLB,RTC,RUDANG,TIR(25)                                           PRP 0110
      CCMMON /VARBLE/ VAL(40)                                           PRP 0120
                                                                        PRP 0130
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),       PRP 0140
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),     PRP 0150
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),PRP 0160
     3(VAL(24),PB)                                                      PRP 0170
      DIMENSION THS(1),THP(1),TS(1),TP(1),RUD(1),TR(1)                  PRP 0180
```

```
      EQUIVALENCE (THSTS(1),THS(1)),(THSTP(1),THP(1)),(TIS(1),TS(1)),(TI
     AP(1),TP(1)),(TIR(1),TR(1)),(DELRUD(1),RUD(1))
      FX = 0.0
      FY = 0.0
      FZ = 0.0
      FK = 0.0
      FM = 0.0
      FN = 0.0

      TL=TIME
      IF(NPR.EQ.0.0) GO TO 5
      RUDANG=FG1(TL,NPR,TR,RUD,IR)
      RUDANG=RUDANG/RAD
C    CALCULATE THRUSTS AND MOMENTS INDIVIDUALLY
      GO TO 6
    5 RUDANG=DELRUD(1)
      RUDANG=RUDANG/RAD
    6 CD=COS(RUDANG)
      SD=SIN(RUDANG)
      IF(NPS.EQ.0.0) GO TO 2
      THSS=FG1(TL,NPS,TS,THS,IS)
      GO TO 4
    2 THSS=THSTS(1)
    4 IF(NPP.EQ.0.0) GO TO 3
      THSP=FG1(TL,NPP,TP,THP,IP)
      GO TO 1
    3 THSP=THSTP(1)
    1 STHSTS=STHS*THSS
      STHSTP=STHP*THSP
      FXS=THSS*CD+STHSTS*SD
      FXP=THSP*CD-STHSTP*SD
      FYS=-STHSTS*CD+SD*THSS
      FYP=STHSTP*CD+SD*THSP
      FZS=-THSS*THETA*CD-STHSTS*CD*PHI
      FZP=-THSP*THETA*CD+STHSTP*CD*PHI
      FX=FXP+FXS
      FY=FYP+FYS
      FZ=FZP+FZS
      FKP=-FZP*YP-FYP*ZP
      FKS=FZS*YP-FYS*ZP
      FK=FKS+FKP
      FMS=FZS*(-XP)+FXS*ZP
      FMP=FZP*(-XP)+FXP*ZP
      FM=FMS+FMP
      FNS=-FXS*YP-FYS*(-XP)
      FNP=FXP*YP-FYP*(-XP)
      FN=FNS+FNP
      IF (IPROP.NE.ON) RETURN
```

```
                 WRITE(6,123)                                          PRP 0670
     1FX,FY,FZ,FK,FM,FN                                                PRP 0680
 123 FORMAT(/10X,22HPROP FX,FY,FZ,FK,FM,FN  /6E15.4)                   PRP 0690
      RETURN                                                           PRP 0700
      END                                                              PRP 0710
C
C                                                                      RHS 0010
      SUBROUTINE RHS(VALUE)                                            RHS 0020
      INTEGER ON                                                       RHS 0030
                                                                       RHS 0040
      COMMON /AIR/ PINF,RHOINF,GAM                                     RHS 0050
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IYRHS 0060
      COMMON /COLUMN/ IVERT,ILATRL                                     RHS 0070
      COMMON /CONST/ PI,RAD,UO                                         RHS 0080
      COMMON /CNTRL/CONTW,CONTQ,CONTTH,QMULT,LCUVER,ACONTZ,ACONTW,ZEQUILRHS 0090
     1 ,THEQL,ACBASE                                                   RHS 0100
      COMMON/ENGINE/NPS,NPP,THSTS(25),THSTP(25),XP,YP,ZP,STHS,STHP,    RHS 0110
     ATIP(25),TIS(25)                                                  RHS 0120
      COMMON /FANMAP/QIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,  RHS 0130
     1 ENSFAN,BRPM,MRPM,SRPM,NPTSB,NPTSM,NPTSS                         RHS 0140
     2 ,PBFAN(25),PMFAN(25),PSFAN(25),TMEB(25),DELB(25),NB,TMES(25),   RHS 0150
     3DETS(25),NS                                                      RHS 0160
      COMMON /FAERO/ FXAED,FYAED,FZAED,FKAED,FMAED,FNAED               RHS 0170
      COMMON /FORBS/FXBS,FYBS,FZBS,FKBS,FMBS,FNBS,QLBS                 RHS 0180
      COMMON /FORSS/FXSS,FYSS,FZSS,FKSS,FMSS,FNSS,QLSS,FMS             RHS 0190
      COMMON /FPROP/ FXP,FYP,FZP,FKP,FMP,FNP                           RHS 0200
      COMMON / FROUDE / FN,FNCRIT                                      RHS 0210
      COMMON /FRUD/ FXRUD,FYRUD,FZRUD,FKRUD,FMRUD,FNRUD                RHS 0220
      COMMON/GBOW/ XBOW                                                RHS 0230
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VCLNOM    RHS 0240
     1,CELS(4,10),XCPO,ZCP                                             RHS 0250
      COMMON /GEOMBS/DETABX(11),DETABT(11),ARM1B(10),ARM2B(10)         RHS 0260
     1 ,DFBS(10),TSKIB(10)                                             RHS 0270
      COMMON /GEOMSS/DETADX(11),DETADT(11),ARM1S(10),DFSS(10),TSKIS(10) RHS 0280
     1 ,ARM2S(10)                                                      RHS 0290
      COMMON /KSWTCH/ ITHRST                                           RHS 0300
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS, RHS 0310
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO      RHS 0320
      COMMON /MATRIX/ A(6,6)                                           RHS 0330
      COMMON /MSIDW/ DF(2,10),DSWAV(2,10),FXH(2),FYH(2),FZH(2),FMH(2), RHS 0340
     1               FNH(2),VFY(2),VFZ(2),FXV                          RHS 0350
      COMMON /MWAVE/ FXW(2),FYW(2),FZW(2),FKW(2),FMW(2),FNW(2)         RHS 0360
      COMMON /OPTION/ I3DOF,ISRGE,ITRIM                                RHS 0370
      COMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT                              RHS 0380
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT                    RHS 0390
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES, RHS 0400
     -IRUD,IPROP,IAEROD,IRHS                                           RHS 0410
      COMMON /PWAVE/ FNCON,PWVCON                                      RHS 0420
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```
      COMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRDS,TL,RSPAN,RAREA,RASPR,
     ARCLB,RTC,RUDANG,TIR(25)
      COMMON /SIDE/FXSW,FYSW,FZSW,FKSW,FMSW,FNSW,ALSW,YSW,XLSW,CFSW,CDSW
     1,VAREA   ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC
      COMMON/SOFTBS/XBF,PBS,SINBS,COSBS,XBS,ZBS,DELYBS,DPBS,ELMAXB,YAVG
     1B(10)
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS
     1 ,ELMAXS,YAVGS(10)
      COMMON / VALOLD /  YOLD(20)
      COMMON /VARBLE/  VAL(40)
      COMMON /WAVE/ ETA(4,11),AW(10),CMEGA(10),CVCLW,NWAVE,BETA,
     1               FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV
     2               ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR

      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),
     3(VAL(24),PB)
      EQUIVALENCE (VAL(18),FANPWR)

      DATA NCTIN /0/
      DIMENSION ACCEL(3),ANGACL(3)
      DIMENSION GF(6),VALUE(20)
      DO 5 J=1,20
    5 VALUE(J)=0.0

      AB=XL*(XBBW-(XBBW-WIDTH)*(ZS+Z)/BUBHGT)
      VCL=VOLNOM-.5*(AB+ABW)*(Z+ZS)-DVOLW
      PB=PINF*(BMASS/(VCL*RHOINF))**GAM
      PBS=PB+DPBS
      PSS=PB+DPSS
      PBAR=PB-PINF
      ABPB=PBAR*AB

C     CALCULATION OF BUBBLE WAVE MAKING DRAG
      FN=U/FNCON
      CF=.50/(FN**1.5655981)
      FXPWAV=-PWVCON*PBBAR*CF
      FLOW=SQRT(2.*ABS(PBAR)/RHOINF)*SIGN(1.,PBAR)
      QLSW=CFSW*ALSW*FLOW

      CALL BOWSL
      CALL STNSL

      GF(1)=FXBS+FXSS+FXSW+FXRUD+FXP+FXWAV+FXAED            +FXPWAV
      IF (ITHRST.NE.ITRIM) GO TO 11

      THSTS(1)=THSTS(1)-GF(1)/2.
```

```
      THSTP(1)=THSTP(1)-GF(1)/2.
      THST=THSTS(1)+THSTP(1)
      IF(ITRIM.EQ.ON)
     1WRITE(6,76) FXBS,FXSS,FXSW,FXRUD,FXP,FXWAV,FXAED,ABPB,FXPWAV,
     ATHST
   76 FORMAT(//10X,3HRHS
     1/42H FX COMPONENTS (AS LISTED IN RHS +THRUST)  /10E13.5)
      GF(1) = 0.0
   11 CONTINUE
      GF(2)=-R*U*AM+FYBS+FYSS+FYSW+FYRUD+FYP+FYWAV+FYAED
      GF(3)=WEIGHT-ABPB          +FZBS+FZSS+FZSW+FZRUD+FZP+FZWAV+FZAED
      GF(4)=FKBS+FKSS+FKSW+FKRUD+FKP+FKWAV+FKAED +ABPB*PHI*(-Z)
C  EFFECTIVE CENTER OF PRESSURE CALCULATION FOR XR-3 ONLY
      XCP=-.05*U**.5925+XCP0
      IF((U**.5925).GT.22.0) XCP=-.023*U**.5925+.262
C
      GF(5)=FMBS+FMSS+FMSW+FMRUD+FMP+FMWAV+FMAED +ABPB*(XCP-THETA*Z )
     -          +FXPWAV*ZS
      FMBUB=ABPB*(XCP-THETA*Z)
      FWAVZ=FXPWAV*ZS
      GF(6)=FNBS+FNSS+FNSW+FNRUD+FNP+FNWAV+FNAED
      IF( I3DOF .NE. 1) GO TO 100
      GF(3)=0.0
      GF(5)=0.0
  100 CONTINUE
      DO 1 I=1,6
      VALUE(I)=0.0
      DO 1 J=1,6
      VALUE(I)=VALUE(I)+A(I,J)*GF(J)
    1 CONTINUE

      VALUE(7)=P
      VALUE(8)=Q
      VALUE(9)=W

      IF (I3DOF .EQ. 1 ) GO TO 325
C     BUBBLE PRESSURE EQUATION
      QCUT=QLBS+QLSS+QLSW
      CALL FAN
      QCNTRL=0.0
      VALUE(10)=RHOINF*(QIN-QCUT-QCNTRL)
      GO TO 236
  325 CONTINUE
      VALUE(10)=0.0
  236 CONTINUE

C     WRITE DATA FILE FOR MOMENT AND SHEAR CALCS., IF REQUIRED
      IF ( IMT.NE.1 )  GO TO 111
```

```
      NBS = NSTA(3)-1
      NSS = NSTA(4)-1
      NSSL = NSS/2+1
                            WRITE (IBMFIL)  (VAL(I),I=1,24),ZBAR,PHIBAR,THEBAR,
     -                      FXW,FYW,FZW,FKW,FMW,FNW,  (VALUE(I),I=1,10),
     -                      DF,DSWAV,FXH,FYH,FZH,FMH,FNH,VFY,VFZ,FXV  ,
     -                      FXRUD,FYRUD,FXP,FYP,FZP,   FZSS,FKSS,FMSS,FXBS,FZBS,
     -                      FXAED,FYAED,FZAED,FMAED,FNAED,FXPWAV,FXSS,FKBS,FMBS
     X ,FNBS, FNSS ,(TSKIS(I),DFSS(I),I=NSSL,NSS)
     Y              ,(TSKIB(I),DFBS(I),ARM1B(I),ARM2B(I),I=1,NBS)
  111 CONTINUE

C     CONSTANT LONGITUDINAL VELOCITY ( U )
      IF (ISRGE .EQ.1) VALUE(1)=0.0

      IF (ON.NE.1) RETURN
      DO 2 I=1,3
      ACCEL(I)=VALUE(I)/G
      ANGACL(I)=VALUE(I+3)*RAD
 2    CONTINUE
      BCWACC=ACCEL(3)-XBCW*VALUE(5)/G
      STNACC=ACCEL(3)+XS*VALUE(5)/G
      IF(IVERT.NE.ON) GO TO 10
      ZD=Z+ZS
      THETAR=THETA*RAD
   10 IF(ILATRL.NE.ON) GO TO 15
      DEPSI=PSI*RAD
      RDEG=R*RAD
      BETAS=-V/U*RAD
      ACCLAT=(VALUE(2)+U*R)/G
      DPHI=PHI*RAD
      DRFT=12.0*ZD
      VEL=0.5925*U
      DELRS=RUDANG*RAD
      IF(R.EQ.0.0) GO TO 115
      TRADUS=U/R
      GO TO 20
 115  TRADUS=1.E8
   20 WRITE(1)TIME,VAL(16),DRFT,THETAR,PBAR,BCWACC,ACCEL(3),FANPWR,CPHI,
     1DEPSI,ACCLAT,VEL,TRADUS,RDEG,X,Y,CIN,QOUT,GF(1),FXPWAV,GF(2),GF(3)
     2,GF(4),GF(5),GF(6),DELRS
 15   IF (IRHS .NE. ON) RETURN
       WRITE(6,77) FMBS,FMSS,FMSW,FMRUD,FMP,FMWAV,FMAED,FMBUB,FWAVZ
   77 FORMAT('0',6X,5HFMBS=,E16.6,2X,5HFMSS=,E16.6,2X,5HFMSW=,
     AE16.6,/,'0',6X,6HFMRUD=,E16.6,2X,4HFMP=,E16.6,2X,6HFMWAV=,E16.6,
     B/,'0',6X,6HFMAED=,E16.6,2X,6HFMBUB=,E16.6,2X,6HFWAVZ=,E16.6)
      WRITE(6,401)FXPWAV
  401 FORMAT('0',6X,7HFXPWAV=,E16.6)
```

```
      WRITE(6,200) PBAR,FANPWR,QIN,QLBS,QLSW,QLSS                       RHS 1870
      WRITE(6,215) AB,VOL                                               RHS 1880
                 WRITE(6,213) VALUE,VAL                                 RHS 1890
      WRITE(6,150) GF,ACCEL,ANGACL                                      RHS 1900
      WRITE(6,175)BOWACC,STNACC                                         RHS 1910
  200 FORMAT(//10X,3HRHS                                                RHS 1920
     120H GAGE PRESS. (PSF) = F7.2,5X,21HFAN POWER REQD (HP) =  F8.2,   RHS 1930
     25X,27HFAN FLOW RATE (CU FT/SEC) =  F9.2,                          RHS 1940
     3//31H LEAKAGE FLOW RATES (CU FT/SEC)  //11H BOW SEAL = F9.2,      RHS 1950
     411H SIDEWALL = F9.2,13H STERN SEAL = F9.2)                        RHS 1960
  215 FORMAT(/13H PLENUM AREA= F9.2,10X,14HPLENUM VOLUME= F10.2)        RHS 1970
  213 FORMAT(//12H VALUE ARRAY 2(/10E13.4)/10H VAL ARRAY 4(/10E13.4))   RHS 1980
  150 FORMAT(/10X,24HTOTAL FORCES AND MOMENTS 6E12.4/10X,24HACCELERATIONRHS 1990
     -S G,DEG/SEC2 6E12.4)                                              RHS 2000
  175 FORMAT(/10X,16HBOW ACCEL. (G) = E12.4,21H   STERN ACCEL. (G) = E12RHS 2010
     -.4)                                                               RHS 2020
      RETURN                                                            RHS 2030
      END                                                               RHS 2040
C
C                                                                       RUD 0010
      SUBROUTINE RUDDER                                                 RUD 0020
      INTEGER ON                                                        RUD 0030
      COMMON /CONST/ PI,RAD,UO                                          RUD 0040
      COMMON /FRUD/ FX,FY,FZ,FK,FM,FN                                   RUD 0050
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,  RUD 0060
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHC       RUD 0070
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,  RUD 0080
     -IRUD,IPROP,IAEROD,IRHS                                            RUD 0090
      COMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRDS,TL,RSPAN,RAREA,RASPR,  RUD 0100
     ARCLB,RTC,RUDANG,TIR(25)                                           RUD 0110
      COMMON /VARBLE/ VAL(40)                                           RUD 0120
                                                                        RUD 0130
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),       RUD 0140
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),     RUD 0150
     2(VAL(10),Z),(VAL(11),EMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),RUD 0160
     3(VAL(24),PB)                                                      RUD 0170
      EQUIVALENCE (DELRUD(1),RUD(1)),(TIR(1),TR(1))                     RUD 0180
      DIMENSION RUD(1),TR(1)                                            RUD 0190
      EQUIVALENCE (VAL(18),FANPWR)                                      RUD 0200
      DATA ENU /1.28E-5/                                                RUD 0210
                                                                        RUD 0220
C     CALCULATE PROGRAMMED RUDDER DEFLECTION                            RUD 0230
      TL=TIME                                                           RUD 0240
      IF(NPR.EQ.0.0) GO TO 5                                            RUD 0250
      GO TO 6                                                           RUD 0260
    5 RUDANG=DELRUD(1)                                                  RUD 0270
      RUDANG=RUDANG/RAD                                                 RUD 0280
      GO TO 7                                                           RUD 0290
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```
    6 RUDANG=FG1(TL,NPR,TR,RUD,IR)
      RUDANG=RUDANG/RAD
C     SIDE FORCE CN RUDDER
    7 DSR=Z+ZS-XR*THETA
      ENDFAC=(1.+DSR/(DSR+RSPAN))
      VH=V+XR*R-ZR*P
      QQ=HRHO*U*U*RAREA
      EFFANG=RUDANG-ENDFAC*VH/U
      FY=2.*QQ*ENDFAC*RCLB*EFFANG

C     DRAG FORCE CN RUDDER
      REY=U*(RAREA/RSPAN)/ENU
      CFR=.427/(ALOG10(REY)-.407)**2.64
      PI8=PI/8.
      CD=2.*CFR+ PI8*RTC*RTC*(1.+G*RSPAN/(U*U))+RCLB*EFFANG*EFFANG
      FX=-2.* CD*RAREA*HRHO*U*U

      FZ=0.
      FK=-ZR*FY
      FM=FX*ZR
      FN=XR*FY
      IF(IRUD.NE.CN) RETURN
                        WRITE(6,123)
     1FX,FY,FZ,FK,FM,FN
  123 FORMAT(/10X,24HRUDDER FX,FY,FZ,FK,FM,FN /6E15.4)
      RETURN
      END
C
C
      SUBROUTINE SAM
      WRITE (6,10)
   10 FORMAT (1H1,'YOU HAVE CALLED A DUMMY SAM SUBROUTINE.'/
     110X,'CHANGE TO BH1SES TC USE THE SAM SUBROUTINE.')
      RETURN
      END
C
C
      SUBROUTINE SIDEWL
      INTEGER ON
      COMMON /AIR/ PINF,RHOINF,GAM
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IY
      COMMON /CONST/ PI,RAD,UO
      COMMON /GEOM/     WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VCLNOM
     1,DELS(4,10),XCP,ZCP
      COMMON /GEOMSW/ XAVG(10),DS
      COMMON /KSWTCH/ ITHRST
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO
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      COMMON /MSIDW/ DF(2,10),DSWAV(2,10),FXH(2),FYH(2),FZH(2),FMH(2),    SWL 0130
     1               FNH(2),VFY(2),VFZ(2),FXV                             SWL 0140
      COMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT                                 SWL 0150
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT                       SWL 0160
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,    SWL 0170
     -IRUD,IPROP,IAEROD,IRHS                                              SWL 0180
      COMMON /SIDE/FX   ,FY   ,FZ   ,FK   ,FM   ,FN   ,ALSW,YSW,XLSW,CFSW,CDSWSWL 0190
     1,VAREA   ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC       SWL 0200
      COMMON /VARBLE/ VAL(40)                                             SWL 0210
      COMMON /WAVE/ ETA(4,11),AW(10),CMEGA(10),DVCLW,NWAVE,BETA,          SWL 0220
     1              FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                   SWL 0230
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSEET,SINBET                  SWL 0240
      COMMON /WAVTAB/ NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB,    SWL 0250
     1         AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),           SWL 0260
     2         AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)                        SWL 0270
     3         ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),                     SWL 0280
     4         AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),           SWL 0290
     5         AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)                        SWL 0300
     6         ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7)                      SWL 0310
     7         ,BB(36),XREF,RX                                            SWL 0320
      EQUIVALENCE              (VAL(2),U),(VAL(3),V),(VAL(4),W),          SWL 0330
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),       SWL 0340
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),SWL 0350
     3(VAL(24),PB)                                                        SWL 0360
      DIMENSION GAP(2,11),DSW(2,11)                                       SWL 0370
                                                                          SWL 0380
      DATA ENU /1.28E-5/                                                  SWL 0390
                                                                          SWL 0400
C     GAP OR WETTED DRAFT CALCULATION                                     SWL 0410
      DC 5 I=1,2                                                          SWL 0420
      DC 5 J=1,11                                                         SWL 0430
      GAP(I,J)=0.0                                                        SWL 0440
      DSW(I,J)=0.0                                                        SWL 0450
    5 CONTINUE                                                            SWL 0460
      DO 10 J=1,2                                                         SWL 0470
      N=NSTA(J)                                                           SWL 0480
      DO 10 K=1,N                                                         SWL 0490
      DD=ZS+Z+YY(J,K)*PHI-XX(1,K)*THETA+ETA(J,K)                          SWL 0500
      IF (DD.LT.BUBHGT)  GC TO 101                                        SWL 0510
      IF ( VAL(1)-TOLD .LT. DELPNT )  GO TO 101                           SWL 0520
      TCLD = VAL(1)                                                       SWL 0530
      WRITE (6,100) XX(J,K),VAL(1),DD                                     SWL 0540
  100 FORMAT(/10X,43HWATER CONTACT WITH TOP OF BUBBLE CHAMBER AT F7.2,    SWL 0550
     -14H FT.     TIME = F7.2,19H SEC.     IMMERSION= F7.2,4H FT. )       SWL 0560
  101 CONTINUE                                                            SWL 0570
      GAP(J,K)=(SIGN(1.,DD)-1.)*DD/2.                                     SWL 0580
      DSW(J,K)=(SIGN(1.,DD)+1.)*DD/2.                                     SWL 0590
   10 CONTINUE                                                            SWL 0600
```

```
                                                                          SWL 0610
C      LEAKAGE AREA                                                       SWL 0620
       ALSW=0.0                                                           SWL 0630
       DC 20 J=1,2                                                        SWL 0640
       N=NSTA(J)-1                                                        SWL 0650
       DC 20 I=1,N                                                        SWL 0660
       ALSW=ALSW+(GAP(J,I)+GAP(J,I+1))*DELX/2.                            SWL 0670
   20  CONTINUE                                                           SWL 0680
                                                                          SWL 0690
C      CRCSS-FLCW DRAG ON SIDEWALLS                                       SWL 0700
       FYD=0.0                                                            SWL 0710
       FKD=0.0                                                            SWL 0720
       FND=0.0                                                            SWL 0730
       DO 15 I=1,2                                                        SWL 0740
       N=NSTA(I)-1                                                        SWL 0750
       DO 15 J=1,N                                                        SWL 0760
       DSWAV(I,J)=(DSW(I,J)+DSW(I,J+1))/2.                                SWL 0770
       VREL      =V+XAVG(J)*R-(ZS-DSWAV(I,J)/2.)*P                        SWL 0780
       DF(I,J)=-  HRHO*CDSW*VREL      *ABS(VREL      )*DELX     *DSWAV(I,J)SWL 0790
       FYD=FYD+DF(I,J)                                                    SWL 0800
       FND=FND+DF(I,J)*XAVG(J)                                            SWL 0810
   15  FKD=FKD-(ZS-DSWAV(I,J)/2.)*DF(I,J)                                 SWL 0820
                                                                          SWL 0830
C      SET UP STERN LIMIT CF FCRCE DETERMINATION                          SWL 0840
       XSS = -XS                                                          SWL 0850
       GC TO 16                                                           SWL 0860
                                                                          SWL 0870
       ENTRY SIDWLM                                                       SWL 0880
       XSS = XMI(IX)                                                      SWL 0890
                                                                          SWL 0900
16     IP=1.+(THETA*RAD-STH)/DTH                                          SWL 0910
       IP=MAXO(MINO(IP,NTH),1)                                            SWL 0920
       IP1=MINO(IP+1,NTH)                                                 SWL 0930
       DTHETA=(IP-1)*DTH+STH                                              SWL 0940
       DIP= (THETA*RAD-DTHETA)/DTH                                        SWL 0950
                                                                          SWL 0960
C      CALC REYNOLDS NO. AND DRAG COEFF.                                  SWL 0970
       REY=U*XLSW/ENU                                                     SWL 0980
       CDT=.427/(ALOG10(REY)-.407)**2.64                                  SWL 0990
                                                                          SWL 1000
C      SIDEWALL FORCES, P/S                                               SWL 1010
       DO 40 J=1,2                                                        SWL 1020
       WAREA=0.0                                                          SWL 1030
       N=NSTA(J)-1                                                        SWL 1040
       NI = (XSS+XS)*N/XLSW+1.5                                           SWL 1050
       DO 21 I=NI,N                                                       SWL 1060
       ZOR1=1.                                                            SWL 1070
       IF(DSWAV(J,I).EQ. 0.0) ZOR1=0.0                                    SWL 1080
```

```
21    WAREA=WAREA+DELX*(2.*DSWAV(J,I)+ZCR1*AVBMSW)
      FXH(J)=-  HRHO*CDT*WAREA*U*U

      PM1=2*J-3
      YLSW=PM1*YSW
      DS= Z    +ZS+YLSW*PHI
      DSS=DS-XSS*THETA
      ZCR1=(SIGN(1.,DSS)+1.)/2.
      DSS=DSS*ZCR1
      IDSS=1.5+(DSS-SBB)/DBB
      IDSS=MINO(NBB,IDSS)
      BS=BB(IDSS)
      ZCR1=(SIGN(1.,DSS)+1.)/2.
      DSS=DSS*ZCR1
      A33S=(RHO*PI*BS**2)/8.
      A22S=(RHO*.4*PI*DSS**2)/2.
      DSR=DS-(XREF-XS)*THETA
      ID=1.+(DSR*12.-SDS)/DDS
      ID=MAXO(MINO(ID,NDS),1)
      DDSR =(ID-1)*DDS  +SDS
      ID1=MINO(ID+1,NDS)
      DID= (DSR*12.-DDSR)/DDS
      BCO=ACO( 1,ID,IP)
      BCOO=ACOO( 1,ID,IP)
      BC2=AC2( 1,ID,IP)
      BC5 = AC5(1,ID,IP)
      BC6 = AC6(1,ID,IP)
      BCO =BCO  +DID*(ACO  (1,ID1,IP)-BCO  ) +DIP*(ACO  (1,ID,IP1)-BCO
     1   +DID*(ACO  (1,ID1,IP1)-ACO  (1,ID,IP1)-ACO  (1,ID1,IP)+BCO  ))
      BCOO=BCOO+DID*(ACOO(1,ID1,IP)-BCOO) +DIP*(ACOO(1,ID,IP1)-BCOO
     1   +DID*(ACOO(1,ID1,IP1)-ACOO(1,ID,IP1)-ACOO(1,ID1,IP)+BCOO))
      BC2 =BC2  +DID*(AC2  (1,ID1,IP)-BC2  ) +DIP*(AC2  (1,ID,IP1)-BC2
     1   +DID*(AC2  (1,ID1,IP1)-AC2  (1,ID,IP1)-AC2  (1,ID1,IP)+BC2  ))
      BC5 =BC5  +DID*(AC5  (1,ID1,IP)-BC5  ) +DIP*(AC5  (1,ID,IP1)-BC5
     1   +DID*(AC5  (1,ID1,IP1)-AC5  (1,ID,IP1)-AC5  (1,ID1,IP)+BC5  ))
      BC6 =BC6  +DID*(AC6  (1,ID1,IP)-BC6  ) +DIP*(AC6  (1,ID,IP1)-BC6
     1   +DID*(AC6  (1,ID1,IP1)-AC6  (1,ID,IP1)-AC6  (1,ID1,IP)+BC6  ))

C     SHIFT MOMENT CENTER FROM XREF TO C.G.
      BCOO = BCOO-(XS-XREF)*BCO
      BC6  = BC6 -(XS-XREF)*BC5

C     HYDROSTATIC AND HYDRODYNAMIC FORCES
      FZH(J) =-G*BCO-U*U*A33S*THETA-U*A33S*W+Q*U*(-BC2+A33S*XSS)
     1   -U*A33S-P*YLSW
      FMH(J) =-U*XSS*XSS*A33S*Q+G*BCOO+U*(A33S*XSS+BC2)*(W+U*THETA
     1  +YLSW*P)
      FYH(J) =-A22S*U*(V+XSS*R   -ZS*P)
```

```
      FNH(J) = FYH(J)*XSS-U*((V-ZS*P)*BC5+R*BC6)
      IF (IMT.EQ.2)  GO TO 40

C     CALC OF FORCE ON VENTRAL FINS REMCVED
39    CONTINUE

40    CONTINUE
      IF (IMT.EQ.2)  RETURN

C     TOTAL SIDEWALL FORCES AMD MOMENTS
      FX=FXH(1)+FXH(2)
      FY=FYH(1)+FYH(2)
      FZ=FZH(1)+FZH(2)
      FK=(FZH(2)-FZH(1))*YSW               +FKD -FY*ZS
      FY=FY+FYD
      FM=FMH(1)+FMH(2)+ZS*FX
      FN= FND +FNH(1)+FNH(2) +(FXH(1)-FXH(2))*YSW

C     DRAG FORCE ON FINS REMOVED
      IF (ISIDWL.NE.ON) RETURN
      DC 41 I=1,2
      DO 41 J=1,11
      GAP(I,J)=12.0*GAP(I,J)
   41 DSW(I,J)=12.0*DSW(I,J)
      WRITE( 6,123) ((GAP(I,J),J=1,11),I=1,2),((DSW(I,J),J=1,11),I=1,2),
     1 FX,FY,FZ,FK,FM,FN
  123 FORMAT(/10X,8HSIDEWALL /25H GAP (FT.) (STERN TO BOW) /14H PORT SID
     1EWALL /11F10.5/14H STBD SIDEWALL /11F10.5/37H IMMERSION DEPTH (FT.
     2) (STERN TO BCW) /14H PORT SIDEWALL /11F10.5/14H STBC SIDEWALL /
     3 11F10.5/10X,26HSIDEWALL FX,FY,FZ,FK,FM,FN /6E15.4)
      RETURN
      END
C
C
      SUBROUTINE STNSL
      INTEGER ON
      COMMON /AIR/ PINF,RHOINF,GAM
      COMMON /CONST/ PI,RAD,UO
      COMMON / FORSS/ FX,FY,FZ,FK,FM,FN,QL,FMS
      COMMON /GEOM/     WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM
     1,DELS(4,10),XCP,ZCP
      COMMON /GEOMSS/DETADX(11),DETADT(11),ARM1S(10),DFSS(10),TSKIS(10)
     1 ,ARM2S(10)
      COMMON /KSWTCH/ ITHRST
      COMMON/LEAKER/ ALEAK,CFSS
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO
```

```
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBCWSL,ISTNSL,IWAVES,
     -IRUD,IPROP,IAERОD,IRHS
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS
     1 ,ELMAXS,YAVGS(10)
      COMMON /STSLR/ CPHI,CPHID
      COMMON / VALOLD / YOLD(20)
      COMMON /VARBLE/ VAL(40)
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVCLW,NWAVE,BETA,
     1              FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR

      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),
     3(VAL(24),PB)
      DIMENSION GAP(11),ELSKI(11)
      DATA ENU,UWSKI,CLSKI  / 1.28E-5, 0.0,  1.5708/
      DO 5 J=1,11
      GAP(J)=0.0
      ELSKI(J)=0.0
    5 CONTINUE
      ALSS=0.0
      FX=0.0
      FZ=0.0
      FK=0.0
      FM=0.0
      FN=0.0
      DELP=PSS-PB
      IF (DELP.LT.0.0) DELP=0.0
      PBAR=PB-PINF


C     CALCULATE ELSKI HERE.
      SINDIF=SINTH-COSTH*THETA
      COSDIF=COSTH+SINTH*THETA
      X1=XSS+ZSS*THETA-XLF*SINDIF
      Z1=(-Z-ZSS+XSS*THETA-XLF*COSDIF)

C     CALCULATE GAP HERE.
      N=NSTA(4)
      DO 10 K=1,N
      ELSKI(K)=(ETA(4,K)-DETADX(K)*(XX(4,K)-X1)-Z1)+YY(4,K)*PHI
      GAP(K)=-ELSKI(K)
      IF (GAP(K) .LT. 0.0) GAP(K)=0.0
   10 CONTINUE

      N=NSTA(4)-1
      DO 20 J=1,N
```

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      ELSKIA=(ELSKI(J+1)+ELSKI(J))/2.                                   SSL 0630
      IF (ELSKIA.LE.0.0) GO TO 15                                       SSL 0640
      IF (ELSKIA.GT.ELMAXS) ELSKIA=ELMAXS                               SSL 0650
      ARM1S(J)=XX(4,J)+ELSKIA/2.                                        SSL 0660
      ARM2S(J)=ZS-ELSKIA                                                SSL 0670
      DFSS(J) =-DELP*ELSKIA*DELYSS                                      SSL 0680
      ARG=.5*RHO*U*U*ELSKIA*DELYSS                                      SSL 0690
      RESKI =U* ELSKIA/ENU                                              SSL 0700
      CDTSKI=.427/(ALOG10(RESKI)-.407)**2.64                            SSL 0710
      TSKIS(J) = - ARG*CDTSKI                                           SSL 0720
      GO TO 18                                                          SSL 0730
   15 DFSS(J) = 0.0                                                     SSL 0740
      TSKIS(J) = 0.0                                                    SSL 0750
                                                                        SSL 0760
   18 CONTINUE                                                          SSL 0770
      FX=FX+TSKIS(J)                                                    SSL 0780
      FZ=FZ+DFSS(J)                                                     SSL 0790
      FK=FK+DFSS(J)*YAVGS(J)                                            SSL 0800
      FM=FM-DFSS(J)*ARM1S(J)+TSKIS(J)*ARM2S(J)                          SSL 0810
      FN=FN-TSKIS(J)*YAVGS(J)                                           SSL 0820
      ALSS=ALSS+(GAP(J)+GAP(J+1))*DELYSS/2.0                            SSL 0830
   20 CONTINUE                                                          SSL 0840
                                                                        SSL 0850
      ALSS=ALSS+ALEAK                                                   SSL 0860
      QL=CFSS*ALSS*SQRT(2.*ABS(PBAR)/RHOINF)*SIGN(1.,PBAR)              SSL 0870
                                                                        SSL 0880
      IF (ISTNSL.NE.ON) RETURN                                          SSL 0890
      WRITE(6,100) GAP,ELSKI,FX,FY,FZ,FK,FM,FN                          SSL 0900
  100 FORMAT(//12H  STERN SEAL /26H  GAP (FT.) PORT TO STBD.  /11E11.3  SSL 0910
     1/28H  ELSKI (FT.) PORT TO STBD.  /11E11.3/10X,23HSTNSL FX,FY,FZ,FKSSL 0920
     2,FM,FN /6E15.4)                                                   SSL 0930
      RETURN                                                            SSL 0940
      END                                                               SSL 0950
C
C                                                                       T1  0010
      FUNCTION T1(X)                                                    T1  0020
      IF(ABS(X)-.1) 10,10,20                                            T1  0030
 10   T1=X*(1.-X*X/10.0)/3.                                             T1  0040
      RETURN                                                            T1  0050
 20   T1=(SIN(X)-X*COS(X))/(X*X)                                        T1  0060
      RETURN                                                            T1  0070
      END                                                               T1  0080
C
C                                                                       T2  0010
      FUNCTION T2(X)                                                    T2  0020
      IF(ABS(X)-.1) 10,10,20                                            T2  0030
10    T2=1.-X*X/6.                                                      T2  0040
      RETURN                                                            T2  0050
```

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20     T2=SIN(X)/X                                                          T2  0060
       RETURN                                                               T2  0070
       END                                                                  T2  0080
C
C                                                                           WVS 0010
       SUBROUTINE WAVES(TIME)                                               WVS 0020
       INTEGER ON                                                           WVS 0030
       COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IYWVS 0040
       COMMON /CONST/ PI,RAD,U0                                             WVS 0050
       COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VCLNOM        WVS 0060
     1,DELS(4,10),XCPO,ZCP                                                  WVS 0070
       COMMON /GEOMBS/DETABX(11),DETABT(11),ARM1B(10),ARM2B(10)             WVS 0080
     1 ,DFBS(10),TSKIB(10)                                                  WVS 0090
       COMMON /GEOMSS/DETADX(11),DETADT(11),ARM1S(10),DFSS(10),TSKIS(10)  WVS 0100
     1 ,ARM2S(10)                                                           WVS 0110
       COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,     WVS 0120
     -              AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO             WVS 0130
       COMMON /MWAVE/ FXW(2),FYW(2),FZW(2),FKW(2),FMW(2),FNW(2)             WVS 0140
       COMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT                                  WVS 0150
       COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,     WVS 0160
     -IRUD,IPROP,IAEROD,IRHS                                                WVS 0170
       COMMON /RISER/ AMPTC                                                 WVS 0180
       COMMON /SIDE/FXSW,FYSW,FZSW,FKSW,FMSW,FNSW,ALSW,YSW,XLSW,CFSW,CDSWWVS 0190
     1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC          WVS 0200
       COMMON /VARBLE/ VAL(40)                                              WVS 0210
       COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVCLW,NWAVE,BETA,           WVS 0220
     1              FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                     WVS 0230
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR              WVS 0240
       COMMON /WAVTAB/ NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB,     WVS 0250
     1           AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),           WVS 0260
     2           AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)                        WVS 0270
     3           ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),                     WVS 0280
     4           AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),           WVS 0290
     5           AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)                        WVS 0300
     6           ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7)                      WVS 0310
     7           ,BB(36),XREF,RX                                            WVS 0320
       DIMENSION WC0(2),WC00(2),WC1(2),WC2(2),WC3(2),WC4(2),WC5(2),WC6(2)WVS 0330
     1          ,WC7(2),WC8(2)                                              WVS 0340
       DIMENSION WS0(2),WS00(2),WS1(2),WS2(2),WS3(2),WS4(2),WS5(2),WS6(2)WVS 0350
     1          ,WS7(2),WS8(2)                                              WVS 0360
       EQUIVALENCE            (VAL(2),U),(VAL(3),V),(VAL(4),W),             WVS 0370
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),         WVS 0380
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),WVS 0390
     3(VAL(24),PB)                                                          WVS 0400
       EQUIVALENCE (VAL(16),ETACG)                                          WVS 0410
                                                                            WVS 0420
       IF (NWAVE.EQ.0) RETURN                                               WVS 0430
                                                                            WVS 0440
```

```
C                                                                      WVS 0450
C    EFFECTIVE CENTER OF PRESSURE CALCULATION FOR XR-3 ONLY            WVS 0460
      XCP=-.05*U*.5925+XCPO                                            WVS 0470
      IF((U*.5925).GT.22.0) XCP=-.023*U*.5925+.262                     WVS 0480
C                                                                      WVS 0490
      GAMMA=BETA-PSI                                                   WVS 0500
      SIGAM=SIN(GAMMA)                                                 WVS 0510
      COGAM=COS(GAMMA)                                                 WVS 0520
      FO= -X*COSBET -Y*SINBET                                          WVS 0530
                                                                       WVS 0540
      DVOLW=0.0                                                        WVS 0550
      ETACG=0.0                                                        WVS 0560
      N=NSTA(3)                                                        WVS 0570
      DO 1 J=1,N                                                       WVS 0580
      DETABX(J)=0.0                                                    WVS 0590
    1 CONTINUE                                                         WVS 0600
      N=NSTA(4)                                                        WVS 0610
      DO 2 J=1,N                                                       WVS 0620
      DETADX(J)=0.0                                                    WVS 0630
    2 CONTINUE                                                         WVS 0640
      DO 10 J=1,4                                                      WVS 0650
      N=NSTA(J)                                                        WVS 0660
      DO 10 K=1,N                                                      WVS 0670
   10 ETA(J,K)=0.0                                                     WVS 0680
      DO 15 J=1,2                                                      WVS 0690
      FXW(J) = 0.0                                                     WVS 0700
      FYW(J) = 0.0                                                     WVS 0710
      FZW(J) = 0.0                                                     WVS 0720
      FKW(J) = 0.0                                                     WVS 0730
      FMW(J) = 0.0                                                     WVS 0740
      FNW(J) = 0.0                                                     WVS 0750
   15 CONTINUE                                                         WVS 0760
                                                                       WVS 0770
      XSS = -XS                                                        WVS 0780
      IF (IMT.EQ.2)  XSS = XMI(IX)                                     WVS 0790
                                                                       WVS 0800
      IP = 1  +(THEBAR*RAD-STH)/DTH                                    WVS 0810
      IP=MAX0(MIN0(IP,NTH),1)                                          WVS 0820
      IP1=MIN0(IP+1,NTH)                                               WVS 0830
      DTHETA=(IP-1)*DTH+STH                                            WVS 0840
      DIP= (THETA*RAD-DTHETA)/DTH                                      WVS 0850
                                                                       WVS 0860
C     TIME RISE FACTOR FOR WAVE AMPLITUDE                              WVS 0870
      AMPFAC=1.-EXP(-TIME/AMPTC)                                       WVS 0880
      DO 100 I=1,NWAVE                                                 WVS 0890
      OM1=OMEGA(I)                                                     WVS 0900
      OM2=OM1*OM1                                                      WVS 0910
      XWK=OM2/G                                                        WVS 0920
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      AA=AW(I)*AMPFAC
      FT= OMI*TIME+XWK*FO
      AL=XWK*COGAM

      IAA= 1+(ABS(AL)-SAL)/DAL
      IAA=MAXO(MINO(IAA,NAL),1)
      IAA1=MINO(IAA+1,NAL)
      DAA= (IAA-1)*DAL+SAL
      DIA= (ABS(AL)-DAA)/DAL
      SALP=SIGN(1.,AL)

C     WAVE FORCES AND MOMENTS ON THE SIDEWALLS
      DO 40 J=1,2
      YLSW=(2*J-3)*YSW
      WE=FT+XWK*SIGAM*YLSW
      ST=SIN(WE)
      CT=COS(WE)
      DS= ZBAR+ZS+YLSW*PHIBAR
      DSR=DS-(XREF-XS)*THEBAR
      ID=1.+(DSR*12.-SDS)/DDS
      ID=MAXO(MINO(ID,NDS),1)
      DDSR =(ID-1)*DDS +SDS
      DID= (DSR*12.-DDSR)/DDS
      ID1=MINO(ID+1,NDS)
      DSS=DS-XSS*THEBAR
      ZOR1=(SIGN(1.,DSS)+1.)/2.
      DSS=DSS*ZOR1
      IDSS=1.5+(DSS-SBB)/DBB
      IDSS=MINO(NBB,IDSS)
      BS=BB(IDSS)
      CK = COS(XWK*COGAM*XSS)
      A33S=(RHO*PI*BS**2)/8.
      SK = SIN(XWK*COGAM*XSS)
      A22S=(RHO*.4*PI*DSS**2)/2.
      A42S=0.0

C     INTERPOLATION OF WAVE TABLES
      K=1
      L=IAA
41    CONTINUE
      BC0=AC0( L,ID,IP)
      BC0C=AC00( L,ID,IP)
      BC1=AC1( L,ID,IP)
      BC2=AC2( L,ID,IP)
      BC3=AC3( L,ID,IP)
      BC4=AC4( L,ID,IP)
      BC5=AC5( L,ID,IP)
      BC6=AC6( L,ID,IP)
```

```
      BC7=AC7( L,ID,IP)                                                  WVS 1410
      BC8=AC8( L,ID,IP)                                                  WVS 1420
      BS0=AS0( L,ID,IP)                                                  WVS 1430
      BS00=AS00( L,ID,IP)                                                WVS 1440
      BS1=AS1( L,ID,IP)                                                  WVS 1450
      BS2=AS2( L,ID,IP)                                                  WVS 1460
      BS3=AS3( L,ID,IP)                                                  WVS 1470
      BS4=AS4( L,ID,IP)                                                  WVS 1480
      BS5=AS5( L,ID,IP)                                                  WVS 1490
      BS6=AS6( L,ID,IP)                                                  WVS 1500
      BS7=AS7( L,ID,IP)                                                  WVS 1510
      BS8=AS8( L,ID,IP)                                                  WVS 1520
      WC0 (K)=BC0 +DID*(AC0 (L,ID1,IP)-BC0 ) +DIP*(AC0 (L,ID,IP1)-BC0    WVS 1530
     1   +DID*(AC0 (L,ID1,IP1)-AC0 (L,ID,IP1)-AC0 (L,ID1,IP)+BC0 ))      WVS 1540
      WC00(K)=BC00+DID*(AC00(L,ID1,IP)-BC00) +DIP*(AC00(L,ID,IP1)-BC00   WVS 1550
     1   +DID*(AC00(L,ID1,IP1)-AC00(L,ID,IP1)-AC00(L,ID1,IP)+BC00))      WVS 1560
      WC1 (K)=BC1 +DID*(AC1 (L,ID1,IP)-BC1 ) +DIP*(AC1 (L,ID,IP1)-BC1    WVS 1570
     1   +DID*(AC1 (L,ID1,IP1)-AC1 (L,ID,IP1)-AC1 (L,ID1,IP)+BC1 ))      WVS 1580
      WC2 (K)=BC2 +DID*(AC2 (L,ID1,IP)-BC2 ) +DIP*(AC2 (L,ID,IP1)-BC2    WVS 1590
     1   +DID*(AC2 (L,ID1,IP1)-AC2 (L,ID,IP1)-AC2 (L,ID1,IP)+BC2 ))      WVS 1600
      WC3 (K)=BC3 +DID*(AC3 (L,ID1,IP)-BC3 ) +DIP*(AC3 (L,ID,IP1)-BC3    WVS 1610
     1   +DID*(AC3 (L,ID1,IP1)-AC3 (L,ID,IP1)-AC3 (L,ID1,IP)+BC3 ))      WVS 1620
      WC4 (K)=BC4 +DID*(AC4 (L,ID1,IP)-BC4 ) +DIP*(AC4 (L,ID,IP1)-BC4    WVS 1630
     1   +DID*(AC4 (L,ID1,IP1)-AC4 (L,ID,IP1)-AC4 (L,ID1,IP)+BC4 ))      WVS 1640
      WC5 (K)=BC5 +DID*(AC5 (L,ID1,IP)-BC5 ) +DIP*(AC5 (L,ID,IP1)-BC5    WVS 1650
     1   +DID*(AC5 (L,ID1,IP1)-AC5 (L,ID,IP1)-AC5 (L,ID1,IP)+BC5 ))      WVS 1660
      WC6 (K)=BC6 +DID*(AC6 (L,ID1,IP)-BC6 ) +DIP*(AC6 (L,ID,IP1)-BC6    WVS 1670
     1   +DID*(AC6 (L,ID1,IP1)-AC6 (L,ID,IP1)-AC6 (L,ID1,IP)+BC6 ))      WVS 1680
      WC7 (K)=BC7 +DID*(AC7 (L,ID1,IP)-BC7 ) +DIP*(AC7 (L,ID,IP1)-BC7    WVS 1690
     1   +DID*(AC7 (L,ID1,IP1)-AC7 (L,ID,IP1)-AC7 (L,ID1,IP)+BC7 ))      WVS 1700
      WC8 (K)=BC8 +DID*(AC8 (L,ID1,IP)-BC8 ) +DIP*(AC8 (L,ID,IP1)-BC8    WVS 1710
     1   +DID*(AC8 (L,ID1,IP1)-AC8 (L,ID,IP1)-AC8 (L,ID1,IP)+BC8 ))      WVS 1720
      WS0 (K)=BS0 +DID*(AS0 (L,ID1,IP)-BS0 ) +DIP*(AS0 (L,ID,IP1)-BS0    WVS 1730
     1   +DID*(AS0 (L,ID1,IP1)-AS0 (L,ID,IP1)-AS0 (L,ID1,IP)+BS0 ))      WVS 1740
      WS00(K)=BS00+DID*(AS00(L,ID1,IP)-BS00) +DIP*(AS00(L,ID,IP1)-BS00   WVS 1750
     1   +DID*(AS00(L,ID1,IP1)-AS00(L,ID,IP1)-AS00(L,ID1,IP)+BS00))      WVS 1760
      WS1 (K)=BS1 +DID*(AS1 (L,ID1,IP)-BS1 ) +DIP*(AS1 (L,ID,IP1)-BS1    WVS 1770
     1   +DID*(AS1 (L,ID1,IP1)-AS1 (L,ID,IP1)-AS1 (L,ID1,IP)+BS1 ))      WVS 1780
      WS2 (K)=BS2 +DID*(AS2 (L,ID1,IP)-BS2 ) +DIP*(AS2 (L,ID,IP1)-BS2    WVS 1790
     1   +DID*(AS2 (L,ID1,IP1)-AS2 (L,ID,IP1)-AS2 (L,ID1,IP)+BS2 ))      WVS 1800
      WS3 (K)=BS3 +DID*(AS3 (L,ID1,IP)-BS3 ) +DIP*(AS3 (L,ID,IP1)-BS3    WVS 1810
     1   +DID*(AS3 (L,ID1,IP1)-AS3 (L,ID,IP1)-AS3 (L,ID1,IP)+BS3 ))      WVS 1820
      WS4 (K)=BS4 +DID*(AS4 (L,ID1,IP)-BS4 ) +DIP*(AS4 (L,ID,IP1)-BS4    WVS 1830
     1   +DID*(AS4 (L,ID1,IP1)-AS4 (L,ID,IP1)-AS4 (L,ID1,IP)+BS4 ))      WVS 1840
      WS5 (K)=BS5 +DID*(AS5 (L,ID1,IP)-BS5 ) +DIP*(AS5 (L,ID,IP1)-BS5    WVS 1850
     1   +DID*(AS5 (L,ID1,IP1)-AS5 (L,ID,IP1)-AS5 (L,ID1,IP)+BS5 ))      WVS 1860
      WS6 (K)=BS6 +DID*(AS6 (L,ID1,IP)-BS6 ) +DIP*(AS6 (L,ID,IP1)-BS6    WVS 1870
     1   +DID*(AS6 (L,ID1,IP1)-AS6 (L,ID,IP1)-AS6 (L,ID1,IP)+BS6 ))      WVS 1880
```

```
      WS7 (K)=BS7 +DID*(AS7 (L,ID1,IP)-BS7 ) +DIP*(AS7 (L,ID,IP1)-BS7   WVS 1890
     1   +DID*(AS7 (L,ID1,IP1)-AS7 (L,ID,IP1)-AS7 (L,ID1,IP)+BS7 ))       WVS 1900
      WS8 (K)=BS8 +DID*(AS8 (L,ID1,IP)-BS8 ) +DIP*(AS8 (L,ID,IP1)-BS8   WVS 1910
     1   +DID*(AS8 (L,ID1,IP1)-AS8 (L,ID,IP1)-AS8 (L,ID1,IP)+BS8 ))       WVS 1920
      IF(K .EQ. 2) GOTO 42                                                WVS 1930
      K=2                                                                 WVS 1940
      L =IAA1                                                             WVS 1950
      GOTO 41                                                             WVS 1960
42    BC0 = WC0 (1)+DIA*(WC0 (2)-WC0 (1))                                 WVS 1970
      BC00= WC00(1)+DIA*(WC00(2)-WC00(1))                                 WVS 1980
      BC1 = WC1 (1)+DIA*(WC1 (2)-WC1 (1))                                 WVS 1990
      BC2 = WC2 (1)+DIA*(WC2 (2)-WC2 (1))                                 WVS 2000
      BC3 = WC3 (1)+DIA*(WC3 (2)-WC3 (1))                                 WVS 2010
      BC4 = WC4 (1)+DIA*(WC4 (2)-WC4 (1))                                 WVS 2020
      BC5 = WC5 (1)+DIA*(WC5 (2)-WC5 (1))                                 WVS 2030
      BC6 = WC6 (1)+DIA*(WC6 (2)-WC6 (1))                                 WVS 2040
      BC7 = WC7 (1)+DIA*(WC7 (2)-WC7 (1))                                 WVS 2050
      BC8 = WC8 (1)+DIA*(WC8 (2)-WC8 (1))                                 WVS 2060
      BS0 =(WS0 (1)+DIA*(WS0 (2)-WS0 (1)))*SALP                           WVS 2070
      BS00=(WS00(1)+DIA*(WS00(2)-WS00(1)))*SALP                           WVS 2080
      BS1 =(WS1 (1)+DIA*(WS1 (2)-WS1 (1)))*SALP                           WVS 2090
      BS2 =(WS2 (1)+DIA*(WS2 (2)-WS2 (1)))*SALP                           WVS 2100
      BS3 =(WS3 (1)+DIA*(WS3 (2)-WS3 (1)))*SALP                           WVS 2110
      BS4 =(WS4 (1)+DIA*(WS4 (2)-WS4 (1)))*SALP                           WVS 2120
      BS5 =(WS5 (1)+DIA*(WS5 (2)-WS5 (1)))*SALP                           WVS 2130
      BS6 =(WS6 (1)+DIA*(WS6 (2)-WS6 (1)))*SALP                           WVS 2140
      BS7 =(WS7 (1)+DIA*(WS7 (2)-WS7 (1)))*SALP                           WVS 2150
      BS8 =(WS8 (1)+DIA*(WS8 (2)-WS8 (1)))*SALP                           WVS 2160
                                                                          WVS 2170
C     SHIFT MOMENT CENTER FROM XREF TO C.G.                               WVS 2180
      BC00 = BC00-(XS-XREF)*BC0                                           WVS 2190
      BC3  = BC3 -(XS-XREF)*BC1                                           WVS 2200
      BC4  = BC4 -(XS-XREF)*BC2                                           WVS 2210
      BC6  = BC6 -(XS-XREF)*BC5                                           WVS 2220
      BS00 = BS00-(XS-XREF)*BS0                                           WVS 2230
      BS3  = BS3 -(XS-XREF)*BS1                                           WVS 2240
      BS4  = BS4 -(XS-XREF)*BS2                                           WVS 2250
      BS6  = BS6 -(XS-XREF)*BS5                                           WVS 2260
                                                                          WVS 2270
C     CALCULATE WAVE FORCES AND MOMENTS                                   WVS 2280
      FZC= BS1-XWK*G*(BS2+BS0)-U*OM1*(-A33S*CK-AL*BS2)                    WVS 2290
      FZS= BC1-XWK*G*(BC2+BC0)+U*OM1*(-A33S*SK+AL*BC2)                    WVS 2300
      FMC= BS3-XWK*G*(BS4+BS00)-U*OM1*(-A33S*XSS*CK-BC2-AL*BS4)           WVS 2310
      FMS= BC3-XWK*G*(BC4+BC00)+U*OM1*(-A33S*XSS*SK-BS2+AL*BC4)           WVS 2320
      FYC= XWK*G*(BC5+BC0)-U*OM1*(-A22S*SK+AL*BC5)                        WVS 2330
      FYS= -XWK*G*(BS5+BS0)-U*OM1*(-A22S*CK-AL*BS5)                       WVS 2340
      FNC= XWK*G*(BC6+BC00)-U*OM1*(-A22S*XSS*SK-BS5+AL*BC6)               WVS 2350
      FNS= -XWK*G*(BS6+BS00)-U*OM1*(-A22S*XSS*CK-BC5-AL*BS6)              WVS 2360
```

```
      FKC=XWK*G*(BC7-BC8)+U*OM1*(-A42S*SK+AL*BC8)
      FKS= -XWK*G*(BS7-BS8)+U*OM1*(-A42S*CK-AL*BS8)
      FZW(J)=FZW(J)-AA*(FZC*CT+FZS*ST)
      FMW(J)=FMW(J)+AA*(FMC*CT+FMS*ST)
      FYW(J)=FYW(J)-AA*(FYC*CT+FYS*ST)*SIGAM
      FNW(J)=FNW(J)-AA*(FNC*CT+FNS*ST)*SIGAM
      FKW(J)=FKW(J)-AA*(FKC*CT+FKS*ST)*SIGAM
      FXW(J)= FXW(J)-2.*AA*RHO*G*BS*DSS*SK*CT
   40 CONTINUE
      IF (IMT.EQ.2)  GO TO 100

C     WAVE ELEVATION AROUND THE SIDEWALLS AND SEALS
      DO 20 J=1,4
      N=NSTA(J)
      DO 20 K=1,N
      ETA(J,K)=ETA(J,K)+SIN(XWK*(- XX(J,K)*COGAM-YY(J,K)*SIGAM)+FT)*AA
20    CONTINUE
      ETACG=ETACG+AA*SIN(FT)
      N=NSTA(3)
      DO 25 J=1,N
      ARG=AA*COS(XWK*(-XX(3,J)*COGAM)+FT)
      DETABX(J)=DETABX(J)-XWK*COGAM*ARG
   25 CONTINUE
      N=NSTA(4)
      DO 30 J=1,N
      ARG=AA*COS(XWK*(-XX(4,J)*COGAM)+FT)
      DETADX(J)=DETADX(J)-XWK*COGAM*ARG
   30 CONTINUE

C     WAVE PUMPING
      X1=XWK*XLBW*COGAM/2.
      X2=XWK*XBBW*SIGAM/2.
      FTT=FT-XWK*XCP*COGAM
      DVOLW=DVOLW+AA*ABW*T2(X1)*T2(X2)*SIN(FTT)

100   CONTINUE
      IF (IMT.EQ.2)  RETURN

C     TOTAL WAVE FORCES AND MOMENTS
      FXWAV=FXW(1)+FXW(2)
      FYWAV=FYW(1)+FYW(2)
      FZWAV=FZW(1)+FZW(2)
      FKWAV=FKW(1)+FKW(2)+(FZW(2)-FZW(1))*YSW      +FYWAV*ZBAR
      FMWAV=FMW(1)+FMW(2)-FXWAV*ZBAR
      FNWAV=FNW(1)+FNW(2)+(FXW(1)-FXW(2))*YSW

      IF (IWAVES.NE.ON) RETURN
                 WRITE(6,200) ((ETA(I,J),J=1,11),I=1,4),ETACG,DVOLW
```

```
     1,FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                              WVS 2850
 200 FORMAT(/10X,5HWAVES /63H WAVE ELEVATIONS AT CRAFT STATIONS RELATIVWVS 2860
     1E TO CALM WATER (FT.) /14H PORT SIDEWALL /11F10.5/14H STBD SIDEWALWVS 2870
     2L /11F10.5/9H BOW SEAL /11F10.5/11H STERN SEAL /11F10.5/25H WAVE EWVS 2880
     3LEVATION AT C.G. = F10.5,10X,43HPLENUM VOLUME LOST DUE TO WAVES (CWVS 2890
     4U. FT.) = F15.5/10X,23HWAVES FX,FY,FZ,FK,FM,FN /6E15.4)           WVS 2900
      RETURN                                                            WVS 2910
      END                                                               WVS 2920
```

APPENDIX C

SAMPLE OUTPUT

```
022
0300
1516C121C122

020

021

00101 18.0      78.0      .001      6.
00102
    1    1    1    1    1    1    1    1    1    1    1
00103
1002
.0001     .0002     .00001    .0000001  .0001     .000001   .000000001.000000001
.0001     .0001
00104
    1    1
00105 0.0       1.0       1.0
00201   5613.0    9.57      2.54    2870.0    9320.0    10580.0   0.0
00301   11.0      11.0      5.0       5.0       24.7
00401   5.37      21.9      .7        1.28      .5
00501   3.97      1.875     20.0      0.90      63.4      1.0       4.06
00601   23.44     0.9       1.0       1.875     63.4      4.06      0.08
00701   20.0      10.0                10.0      20.0      10.4      1.915
00702   0.556
00801   -1.275    5.55      -0.604    275.0     0.0
00901   -1.125    5.55      -0.208    1.07      2.47      .646      .167
01000   20.0      10.0
01101   0.0
01200 25.       .03       5.5       24.75
01601   257.0             .01
01602   257.0             .01
01603   0.
018
 INITIAL RUN XR-3 CALM WATER
01901 2.0       2515.0    24.0      1.
 0.0       4.0       9.0       14.0      13.5      22.0      25.0      26.0
 27.5      29.5      31.0      33.0      34.0      34.5      35.0      35.5
 36.0      37.0      38.0      40.0      41.0      42.0      43.0      44.0
 143.75    137.5     131.25    125.0     118.75    112.5     106.25    100.0
 93.75     87.5      81.25     75.0      68.75     62.5      56.25     50.0
 43.75     37.5      31.25     25.0      18.75     12.5      6.25      0.0
01902 2.0       2515.0    24.0      1.
 0.0       4.0       9.0       14.0      18.5      22.0      25.0      26.0
 27.5      29.5      31.0      33.0      34.0      34.5      35.0      35.5
 36.0      37.0      38.0      40.0      41.0      42.0      43.0      44.0
 143.75    137.5     131.25    125.0     118.75    112.5     106.25    100.0
 93.75     87.5      81.25     75.0      68.75     62.5      56.25     50.0
 43.75     37.5      31.25     25.0      18.75     12.5      6.25      0.0
01903 1.0       2515.0    24.0      1.
 0.0       4.0       9.0       14.0      18.5      22.0      25.0      26.0
 27.5      29.5      31.0      33.0      34.0      34.5      35.0      35.5
 36.0      37.0      38.0      40.0      41.0      42.0      43.0      44.0
 143.75    137.5     131.25    125.0     118.75    112.5     106.25    100.0
 93.75     87.5      81.25     75.0      68.75     62.5      56.25     50.0
 43.75     37.5      31.25     25.0      18.75     12.5      6.25      0.0
013
01200 27.5      .01       5.25      24.75
013
01200 30.       0.        5.        24.75
013
014
```

```
SES MOTIONS AND LOADS PROGRAM -  INITIAL RUN XR-3 CALM WATER

START AND FINISH TIMES       18.00       78.00
INITIAL TIME INTERVAL         0.0010
START PRINTING AT    24.00 IN INCREMENTS OF     6.00
INTERMEDIATE PRINT TAGS    1    1    1    1    1    1    1    1    1    1    1
PROGRAM OPTION SWITCH SETTINGS (LATERAL PLANE,CONSTANT SPEED,TRIM)      0    1    1
NO. OF STATE EQUATIONS, AND TOLERANCES    10
          0.10E-03    0.20E-03    0.10E-04    0.10E-05    0.10E-03    0.10E-05    0.10E-08    0.10E-08    0.10E-03    0.10E-03
WEIGHT, C.G., INERTIA MOMENTS      5813.000       9.570       2.540    2870.000    9320.000   10580.000       0.0
INERTIA MATRIX, AIMAX          0.5534E-02   0.0          0.0          0.0          0.0          0.0
                               0.0          0.5534E-02   0.0          0.0          0.0          0.0
                               0.0          0.0          0.5534E-02   0.0          0.0          0.0
                               0.0          0.0          0.0          0.3484E-03   0.0          0.0
                               0.0          0.0          0.0          0.0          0.1073E-03   0.0
                               0.0          0.0          0.0          0.0          0.0          0.9452E-04
                               0.1058E 05
NUMBER OF STATIONS, SIDEWALLS (P+S), SEALS (B+S)    11    11     5     5
SIDEWALL INPUT    5.370    21.900    0.700    1.230    0.0    0.0    0.0    0.0    0.0    0.0    0.500    0.0
SIDEWALL TABLE PARAMETERS   20   0.100   0.0     5   5.000   2.000    7   1.000  -3.000   31   0.060   0.0

MOMENT CALC. CONTROL PARAMETERS     0     0     0     0   0.0     0

PLENUM, LENGTH AND WIDTH AT WATER      20.0000      10.0000
PLENUM, LENGTH AND WIDTH AT HULL       20.0000      10.0000
PLENUM, CENTER OF PRESSURE AT HULL     10.4000
PLENUM, NOMINAL VOLUME         383.0          HEIGHT        1.9150
PLENUM, INITIAL PRESSURE, GAGE (PSF)     24.75

CRITICAL FROUDE NUMBER           0.5560        TOTAL CRAFT LENGTH        24.7000

FANS, NO. + RPM, BOW,MAIN,STERN          2.     2615.0        2.     2615.0        1.     2615.0

RUDDER, X, Y, Z COORDINATES       -1.1250       5.5500      -0.2080
RUDDER, CN, MAX, RATE, REVERSE, INITIAL         0.0          0.0          0.0          0.0          0.0
RUDDER,SPAN,ASPECT,AREA,CLB,T/C         1.0700       2.4700       0.6460       2.8372       0.1670

PROPULSION, X, Y, Z COORDINATES        -1.2750        5.5500       -0.6040

AERODYNAMICS INPUT       20.0000      10.0000
BOWSEAL INPUT          23.4500       0.9000       1.0000       1.8179
STERNSEAL INPUT         3.9700       1.8750      26.0000       0.9000      63.4000       1.0000       4.0600

INITIAL CONDITIONS, VELOCITY (KNOTS) =  25.00     PITCH (DEG) =    0.030     DRAFT (IN) =     5.50

CALM WATER

XX AND YY ARRAYS
PORT SIDEWALL
   -9.57    -7.23    -4.88    -2.54    -0.19     2.15     4.49     6.84     9.18    11.53    13.87
   -5.37    -5.37    -5.37    -5.37    -5.37    -5.37    -5.37    -5.37    -5.37    -5.37    -5.37
STBD. SIDEWALL
   -9.57    -7.23    -4.88    -2.54    -0.19     2.15     4.49     6.84     9.18    11.53    13.87
    5.37     5.37     5.37     5.37     5.37     5.37     5.37     5.37     5.37     5.37     5.37
BOW SEAL
    9.90     9.90     9.90     9.90     9.90     0.0      0.0      0.0      0.0      0.0      0.0
   -5.00    -2.50     0.0      2.50     5.00     0.0      0.0      0.0      0.0      0.0      0.0
STERN SEAL
   -9.57    -9.57    -9.57    -9.57    -9.57     0.0      0.0      0.0      0.0      0.0      0.0
   -5.00    -2.50     0.0      2.50     5.00     0.0      0.0      0.0      0.0      0.0      0.0
```

```
          TIME (SEC) =  18.00

          TRANSLATIONAL VELS (KTS)/(FT/SEC)
          U= 25.02      V=  0.0      W= 0.0

          ROTATIONAL VELOCITIES (DEG/SEC)
          P=  0.0       Q=  0.0      R=  0.0

          DISPLACEMENTS (FT AND DEGREES)
          Z= -2.032     PHI=  0.0    THETA=  0.03

          TRAJECTORY (FT AND DEGREES)
          X=    0.0     Y=    0.0     PSI=    0.0

          SIDESLIP ANGLE (DEG) =     0.0          RUDDER ANGLE (DEG) =    0.0          THRUST (LBS) =         0.0

          SIDEWALL
GAP (FT.) (STERN TO BOW)
PORT SIDEWALL
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
STBD SIDEWALL
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
IMMERSION DEPTH (FT.) (STERN TO BOW)
PORT SIDEWALL
   5.56014   5.54541   5.53068   5.51595   5.50123   5.48650   5.47177   5.45704   5.44232   5.42759   5.41286
STBD SIDEWALL
   5.56014   5.54541   5.53068   5.51595   5.50123   5.48650   5.47177   5.45704   5.44232   5.42759   5.41286
          SIDEWALL FX,FY,FZ,FK,FM,FN
   -0.2501E 03    0.0          -0.5547E 03    0.0          -0.1447E 04    0.0

          PROP FX,FY,FZ,FK,FM,FN
    0.5140E 03    0.0          -0.2691E 00    0.0           0.1613E 04    0.0

          RUDDER FX,FY,FZ,FK,FM,FN
   -0.4370E 02    0.0            0.0          0.0          -0.1201E 03    0.0

          AERO FX,FY,FZ,FK,FM,FN
   -0.5511E 02    0.0          -0.1653E 03    0.0           0.1017E 04    0.0


          BOW SEAL
GAP (FT.) (PORT TO STBD.)
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
ELSKI (FT.) (PORT TO STBD.)
   0.39588   0.39588   0.39588   0.39588   0.39588   0.0       0.0       0.0       0.0       0.0       0.0
          BCASL FX,FY,FZ,FK,FM,FN
   -0.3017E 02    0.0          -0.9796E 02    0.0           0.9245E 03    0.1526E-04
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STERN SEAL
GAP (FT.) PORT TO STBD.
0.0         0.0        0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
ELSKI (FT.) PORT TO STBD.
0.406E 00  0.406E 00  0.406E 00  0.406E 00  0.406E 00  0.0         0.0         0.0         0.0         0.0         0.0
       STNSL FX,FY,FZ,FX,FM,FN
  -0.3079E 02      0.0              -0.4661E 01      0.0             -0.1037E 03   0.1526E-04

        RHS
FX COMPONENTS (AS LISTED IN RHS +THRUST)
-0.30172E 02 -0.30791F 02 -0.25011E 03 -0.43702E 02  0.51400E 03  0.0        -0.55112E 02  0.49489E 04 -0.10120E 03  0.51109E 03

FAN
Q - BOW,MAIN,STERN (CU FT /SEC)        121.1        133.1        60.6
DELP - BOW,MAIN,STERN (PSF)       33.08       32.57       33.88

     FMBS=    0.924475E 03  FMSS=   -0.103743E 03  FMSW=   -0.144660E 04

     FMPUD=   -0.120042E 03  FMP=     0.161310E 04  FMWAV=     0.0

     FMAED=    0.101744E 04  FMEUB=   -0.154552E 04  FWAVZ=   -0.257059E 03

     FXPWAV=   -0.101204E 03

       RHS GAGE PRESS. (PSF) =  24.74      FAN POWER REQD (HP) =    14.49      FAN FLOW RATE (CU FT/SEC) =   314.80
LEAKAGE FLOW RATES (CU FT/SEC)
BOW SEAL =     10.39 SIDEWALL =      0.0  STERN SEAL =   300.06
PLENUM AREA=   200.00           PLENUM VOLUME=     291.33

VALUE ARRAY
  0.0          0.0          0.1759E 00   0.0          0.3798F-02   0.2884E-08   0.0          0.0          0.0          0.1036E-01
  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
VAL ARRAY
  0.1800E 02   0.4222E 02   0.0          0.0          0.0          0.0          0.0          0.0          0.5236E-03  -0.2082E 01
  0.6986E 00   0.0          0.0          0.0          0.0          0.0          0.0          0.1449E 02   0.0          0.0
  0.0          0.0          0.0          0.2141E 04   0.0          0.0          0.0          0.0          0.0          0.0
  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
       TOTAL FORCES AND MOMENTS  0.0        0.0        0.3179E 02  0.0        0.8200E 02  0.3052E-04
       ACCELERATIONS G,DEG/SEC2  0.0        0.0        0.5463F-02  0.0        0.5041E 00  0.1653E-06

       BOW ACCEL. (G) =  0.1330E-02   STERN ACCEL. (G) =  0.8085E-02

       TOTAL LATERAL ACCELERATION (G) =      0.0              DT =      0.1000E-02
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BIBLIOGRAPHY

1. Aerojet General Corp., Report No. 9132FR-1, May 1969, Aerojet General Corp., El Monte, California.

2. Aerojet General Corporation, Surface Effects Ships Craft Dynamics Program, Project Notebook, Sections 2.1, 3.1, 3.2, 3.3, 3.4, 3.5, 5.2, 5.3, Aerojet General Corp., El Monte, California.

3. Barnaby, Kenneth C., Basic Naval Architecture, Hutchinson and Co., 1949.

4. Baxter, Brian Newland, Naval Architecture: Examples and Theory, Charles Griffin and Company Ltd., 1967.

5. Cagle, Lonnie F., Some Performance Characteristics of the Bell 100 Ton Surface Effect Ship, M. S. Thesis, Naval Postgraduate School, June 1973.

6. Goodyear Aerospace Corporation Report GER-14961, Volume 1, dated 28 January 1971.

7. Kerr, K. P., Study of Steering and Control Devices for Surface Effect Ships - Volume I - Analysis, Lockheed Missiles and Space Co., Report lmsc/do 32092, Dec. 1970.

8. Myers, Kenneth Randall, Turning Characteristics of the Bell 100 Ton Surface Effects Ship, M.S. Thesis, Naval Postgraduate School, June 1973.

9. Oceanics Incorporated, Report No. 71-84, August 1971, Technical Industrial Park, Plainview, N. Y. 11803.

10. Olmstead, John Allen, Performance Testing of a Captive Air Bubble Testcraft, M. S. Thesis, Naval Postgraduate School, June, 1972.

11. Struck, Allen Peter, Pressure Distribution of a Captured Air Bubble Testcraft, M. S. Thesis, Naval Postgraduate School, September, 1972.

12. SES XR-3 Model Stern Seal Assembly, Drawing number A149550 Sheet 2 Of 2, Aerodynamics Laboratory, Naval Ship R&D Center, Department of the Navy, Carderock, Maryland.

13. SKEG - Manned CAB, Code Identification Number 38597, Sheet SK81540-1009 dated May 4, 1966, Martin Company, The aerospace Division of Martin Marietta Corporation, Friendship International Airport, Maryland.

14. SKEG - Manned CAB, Code Identification Number 38597, Sheet SK81540-1007-5,6,7,2, dated May 17, 1966, Martin Company, The Aerospace Division of Martin Marietta Corporation, Friendship International Airport, Maryland.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The digital computer simulation of the six degrees of freedom equations of motion for the XR-3 captive air bubble testcraft is presented. The origin of this computer program is the SES Loads and Motion Program developed by Oceanics Inc. for the Bell 100 ton (100B) surface effect ship. Modifications and procedures used in the revision of the subroutines to convert the L & M Program from the 100B model to the XR-3 model is documented. Measurement

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data from XR-3 test runs are used to verify the model for steady-state operating conditions in calm water. Computer output for turn maneuvers in calm waters and for regular sea conditions are included.

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